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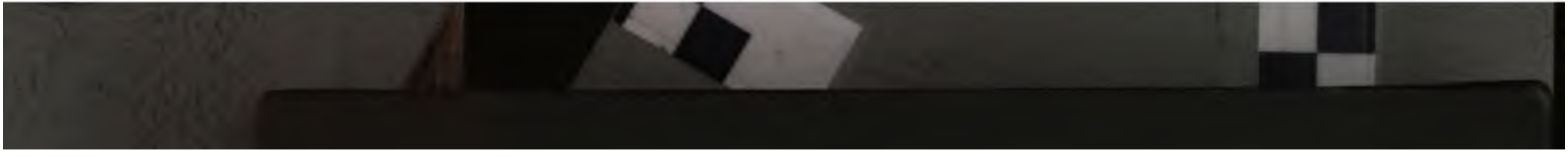

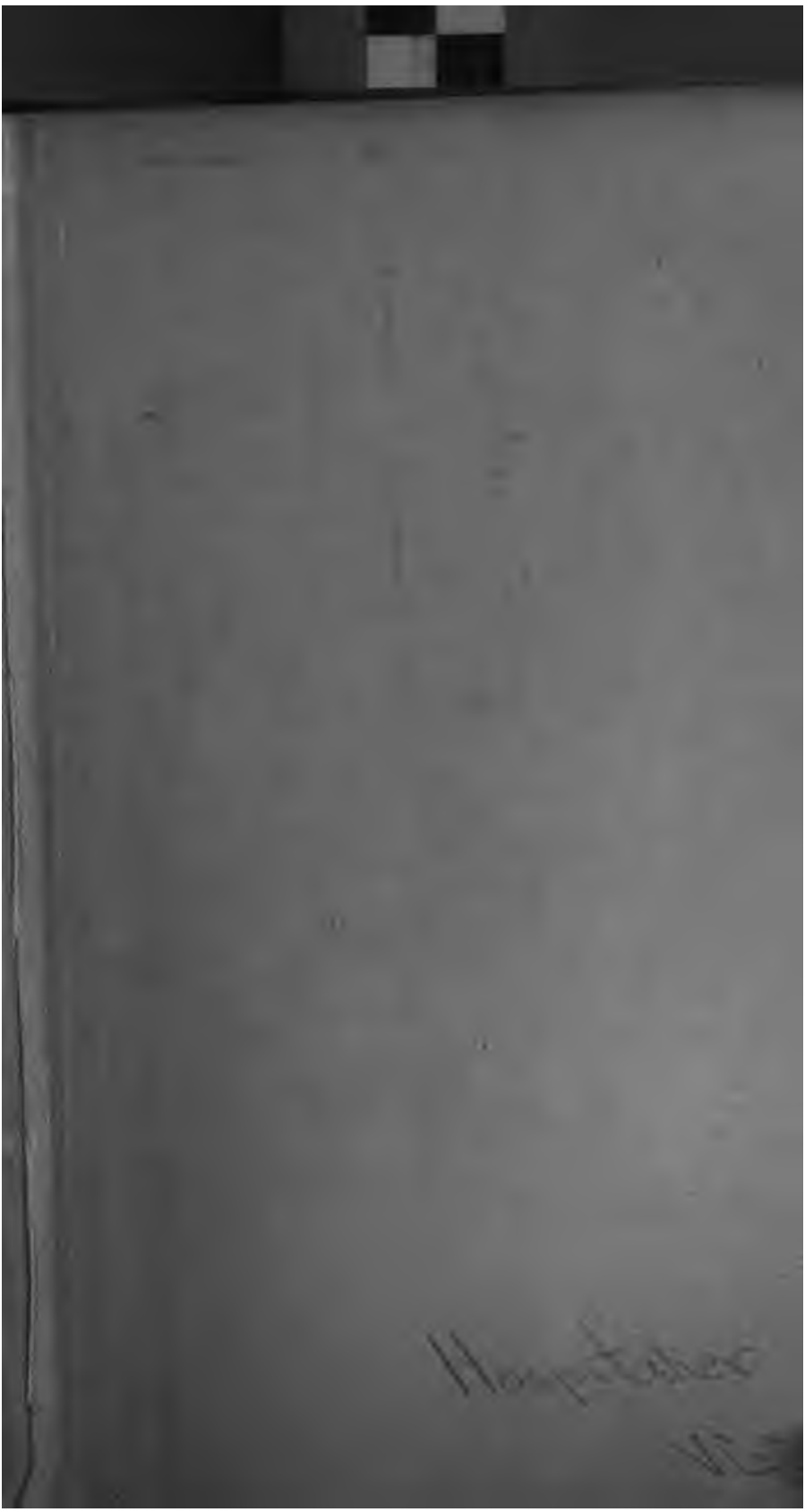

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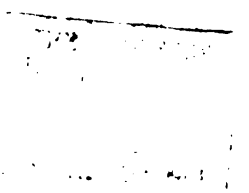

Frontispiece.] SIEMEN'S ELECTRIC TRAMWAY. [*Page* 444.

THE MODERN APPLICATIONS

OF

ELECTRICITY

BY

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WITH NUMEROUS ILLUSTRATIONS

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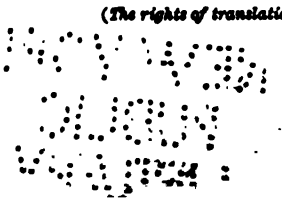

PREFACE.

THE rapid strides which the practical applications of electricity have made within the last few years are without precedent in the history of science. Five years ago a book like the present one would have had no *raison d'être;* at this moment it requires no introduction and no recommendation.

The Electrical Exhibition recently held at Paris not only opened the eyes of the general public, it astonished even the *savants;* it brought home to everybody the irresistible conviction that electrical appliances are destined to play a most important part in the future, and that we shall before long be dependent upon these appliances, not only for our comforts, but even for the necessities of daily life.

While translating Hospitalier's book, which appeared at the beginning of last year, it became quite clear to me that a number of most important additions were necessary, to keep pace with the numerous discoveries that were made during the past twelve months and exhibited in the Palais de l'Industrie, at Paris.

That my idea was shared by the French editor was proved by the appearance of a second edition, when I had just finished my translation. The present book is founded on the second edition, which contains several of the additions

which I had projected; but over and above these, the translation contains a more complete account of Edison's, Lane Fox's, and Brush's systems; an account of Joël's improved Werdermann's lamp, the Pilsen lamp, Hughes' induction balance; Liveing's, Somzée's, and Monnier's apparatus for indicating the presence of fire-damp in coal-mines; Bright's street fire-alarm and district telegraph; the application of electric light in coal-mines and in horticulture, the phonograph, Dolbear's telephone, Kelway's electric log, the electro-metallurgy of zinc, the rectification of alcohol by electricity, etc.

In conclusion, I must express my best thanks to my colleague, Mr. A. S. Davies, for his valuable assistance in the translation of some of the technical terms.

JULIUS MAIER.

CHELTENHAM,
April, 1882.

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THE PRINCIPAL APPLICATIONS OF ELECTRICITY.

PART I.

THE SOURCES OF ELECTRICITY.

THE first electric phenomenon is mentioned by Thales of Miletus, who observed, 600 B.C., that amber, after being rubbed, acquired the property of attracting light bodies; but Otto de Guéricke, towards the middle of the seventeenth century, was the first to observe the electric spark.

The identity of lightning and electricity was not demonstrated until a century later, in 1752, by the illustrious Franklin; and fifty years after that, Volta inaugurated, by the construction of the electric pile, a new era in the history of electricity, the field of which has been so immensely widened during the last few years.

The whole of the eighteenth century is full of studies and discoveries in statical electricity, and it was reserved for Volta to lay the foundation of the numerous discoveries in dynamical electricity. This distinction has almost disappeared, and we shall see in the following chapters how the so-called statical electricity is changed into dynamical electricity, and *vice versâ*.

From the point of view of practical application—the only

part of electricity which interests us in this work—the electrical machines (friction machines, etc.) have given no results, and the high-tension currents which they give have only been used for amusing experiments, for lecture purposes, and for purely scientific research.

We shall, therefore, not consider them, but refer our readers to the treatises on elementary physics, where they will find these phenomena described at length. We are solely concerned with the different modes for producing so-called dynamical electricity, and with its principal applications.

Classification of the Sources of Electricity.—All the apparatus used till now for the production of an electric current can be divided into three large, perfectly distinct classes, characterized by the nature of the action which comes into play.

1. Apparatus in which chemical action is utilized, and which directly transform chemical affinity into electricity. These are galvanic piles, or galvanic batteries.

2. Apparatus which directly transform *heat* into electricity. These are thermo-electric batteries.

3. Apparatus which directly transform *work* into electricity. These are electro-dynamic machines; and they are subdivided into magneto-electric and dynamo-electric machines.

We shall deal separately with these three distinct classes of apparatus; in a special chapter we shall consider those electrical apparatus which are not, properly speaking, generators of electricity, but which impart to the electric current particular properties by changing its relative qualities.

CHAPTER I.

ELECTRIC BATTERIES.

We can form a fairly exact idea of a battery by comparing it to a focus of heat; for instance, the furnace of a boiler. This focus produces, by the combustion or chemical combination of coal with the oxygen of the atmosphere, heat, which raises a certain volume of the products of combustion to a certain temperature.

The amount of heat produced by the combustion will partly serve to produce a certain volume of steam at a certain pressure.

The furnace of our boiler is nothing but the battery itself; zinc is the fuel, dilute acid is the burning agent. By their chemical combustion an electric current is produced, having a certain tension or electro-motive power, and a certain intensity, as vapour has a perfectly distinct volume and pressure.

This crude comparison is on the whole fairly accurate; it enables us to understand the often complicated phenomena connected with the battery, and renders, as it were visible, facts whose theoretical explanation often presents great obscurity.

The simplest form that can be given to a battery is that of a battery with a single liquid. An element consists in that case of—

1. A vessel containing the acting materials;

2. A material to be acted upon (zinc is almost exclusively used), forming the negative pole of the battery: the fuel;

3. A liquid, for instance dilute sulphuric acid: the burning agent;

4. A blade not attacked by the acid—copper, carbon, or platinum—which forms the positive pole on receiving the electricity from the liquid by conduction.

Fig. 1 represents a simple element thus constituted: a glass vessel V; a zinc blade Z, forming the negative pole of the battery; a liquid, water with $\frac{1}{10}$ of its weight of sulphuric acid; and a copper blade C, receiving by conduction the polarity of the liquid in order to form the positive pole. On connecting, by a conducting wire, the two blades Z and C, an electric current will circulate through this wire.

Fig. 1.—Simple element.

This electric current can be simply represented as a circulation of continuous electricity, going from the negative to the positive pole in the interior of the battery, and from the positive to the negative pole on the exterior by means of the connecting wires.

Let us for a moment put aside the secondary phenomena produced in the interior of the simple element which we have described, and examine the current circulating in the outside circuit.

Tension, Electro-motive Power, Intensity of the Electric Current, Resistance of the Conductor.—When a zinc blade

comes in contact with the acid, a difference of electric tension is produced between them, constituting the electro-motive power of the element.

The tension of the current corresponds to the pressure which causes water to circulate through a conducting tube. The analogy is complete, for the intensity of the current in the circuit is analogous to the volume of water delivered by conduction. The conductor forming the outside circuit is nothing else but the conducting tube; this conductor offers a resistance to the electric current as the tube offers a resistance to the running of the water. There are therefore, with regard to a given electric circulation, three distinct characteristic elements—

1. The pressure of the current, tension, electro-motive force, or difference of the potentials, whichever you like to call it; the force through which the electric current is established.

2. The volume of the current, its intensity, or the quantity of electricity traversing the circuit in a given time.

3. The resistance of the circuit, the resistance which the conductor opposes to the circulation of the current, taking into consideration its dimensions and its nature.

Ohm's Law.—The law which connects the resistance of the conductor, the tension, and the intensity of the current in an electric circuit, has been established mathematically by Ohm, a celebrated German savant, in 1827, and experimentally by the French physicist Pouillet.

This law can be expressed very simply by the following formula:—

$$I = \frac{E}{R}$$

where I represents the intensity of the current, E the

electro-motive force or difference of tension at the two extremities of the circuit, R the electric resistance of the circuit.

This formula expresses: The intensity of a current in an electric circuit is in direct proportion to the electro-motive force, and in inverse proportion to the resistance.

We shall have to refer to this law on many occasions in examining the sources of electricity and its applications.

Electrical Units.—We know that a current which traverses an electric circuit of a certain resistance possesses a certain tension, and a fixed intensity. To have an exact idea of this current, we must measure its elements: tension, quantity, and resistance. The measuring of electric elements is a very delicate and difficult task, and is beyond our province, but we must say a few words about the units which have been fixed upon after continued research, and which seem likely before long to be universally adopted.

In 1863, the British Association appointed a committee, composed of the most eminent electricians of Great Britain, to fix upon a standard for electric measurement. After eight years of work, the committee published a very detailed report, and fixed upon the electrical units, guided by considerations upon which we cannot enter here.

The units adopted by the English Commission were founded on the centimetre, the gramme, and the second. They are all derived from one another by definitions which are sometimes of a very complicated nature, but which present the advantage of clearly establishing these units, and allow of their being fixed anew, in case it should be necessary.

But these units possess a still greater advantage over the empirical units which were formerly in use. They require no other coefficient of reduction but multiples of

ten. The introduction of these coefficients of reduction arises from the fact that the original units, to which the committee has given the name of absolute units, were rather too small for practice, which necessitated the use of large numbers in calculation; decimal multiples of these units have been substituted for them, and these multiples have been named after men celebrated in electric science.

The unit of resistance adopted by the committee is the Ohmad (Ohm). It corresponds to the resistance of an iron wire of four millimetres diameter and about a hundred metres in length. In France, it is the custom—a custom which is gradually disappearing—to count the electrical resistance in kilometres of telegraph wire. The kilometre of wire is equivalent to about ten ohms. In Germany, the Siemens unit is used, represented by the resistance of a column of purified mercury, one metre long and one millimetre square in section: it is nearly equal to the ohm.

The unit of tension, or of electro-motive force, takes the name of Volt. It corresponds very nearly to the electro-motive force generated by one Daniell element whose exact value in volts is 1·079. Sometimes the thermo-electric unit of Gaugain is used, whose electro-motive force is $\frac{1}{182 \cdot 8}$ of a volt, and $\frac{1}{197}$ of the Daniell element.

This is the electro-motive force developed by a thermo-electric couple of copper and bismuth, one of the solderings of which is kept at 0° and the other at 100° C.

This unit, now almost obsolete, has the advantage, from a scientific point of view, of being very constant, and of allowing at all times of a practical determination without any difficulty The use of the volt, however, of which there is no real standard, is preferred on account of the simplicity which its use introduces into calculation.

Unit of intensity. It is defined by Ohm's formula—

$$I = \frac{E}{R}.$$

It takes the name of Weber or Ampère. In telegraphic appliances, where the intensities are very feeble, the milliampère, which is the thousandth part of the ampère, is always taken as unit. A telegraphic current varies between five and ten milliampères intensity, an intensity which is quite sufficient to conveniently set in action the lever of an ordinary Morse.

With regard to intensity, a distinction must be drawn without which two very different things might be confounded.

The ampère is really a perfectly distinct quantity of electricity, as a litre is a definite volume and a kilogramme an equally definite weight. If we say that the intensity of the current traversing a wire is one ampère, we mean by that that the quantity of the current traversing this wire during one second, if the current preserves the same intensity, is one ampère. The word "second" is therefore always self-understood when we speak of the intensity of a current. The analogy is complete if we compare, as we have done before, an electric current with a flow of water. The rate of discharge of a flow of water corresponds to the intensity, as for instance a hundred litres per second, and the volume discharged in a given time corresponds to the electric quantity in a given time. This electric quantity is called current. As regards the word "intensity," it corresponds to what the French call "tension." These analogous terms lead to confusion, against which we have to guard ourselves.

These ideas, however philosophical, have not yet been adopted in the French course of instruction, while

they are quite recognized in England. The mechanical theory of heat, with which the electrical phenomena and Joule's law are connected, has confirmed this idea; and the transmission of electric force to a distance, of which we shall speak at the end of this volume, will not be enabled to make any really scientific progress till we have rendered to ourselves a clear account of the relations existing between the different electrical and mechanical agents which come into play in these phenomena.

Unit of quantity. It takes the name of Coulomb, and represents the quantity of electricity which traverses, during one second, a conductor of one ohm resistance with a difference of potential of one volt.

This enables us at once to establish the relation between the intensity of a current and the quantity of electricity. A current with an intensity of one ampère yields per second a quantity of electricity equal to one coulomb. A current with an intensity of $\frac{1}{100}$ ampère will yield a quantity of electricity equal to one coulomb in 100 seconds, etc.

The currents employed in telegraphy vary between five and ten milliampères; those which serve for the electric light vary between one and fifty ampères; finally, in certain electro-chemical operations, the intensity of the current reaches 1000 ampères. It is most essential to employ very intense currents for these operations, because the quantity of metal deposited is proportional to the intensity of the current, that is to say, to the quantity of electricity which passes during a unit of time.

Joule's Law.—The law discovered by the celebrated physicist Joule is expressed by the formula—

$$W = I^2Rt.$$

The quantity of heat or of work W developed by an

electric circuit is proportional to the square of the intensity of the current I, to the resistance of the circuit R, and to the time *t*.

If we introduce the quantity of electricity Q, eliminating time, we have—

$$W = Q^2R.$$

This formula gives, on replacing R by its value taken from Ohm's formula—

$$W = QE.$$

The work is proportional to the quantity of electricity and to the electro-motive force. We find here again the analogy with the flow of water, where the work is proportional to the volume and to the pressure or height of the fall.

Unit of capacity. It takes the name of Farad, and represents the capacity of a condenser which contains one coulomb of electricity when charged to the potential of one volt. The quantity of electricity contained in a condenser is proportional to the pressure, as in a reservoir of compressed air the weight of the enclosed air is proportional to the pressure, always supposing that the air follows Mariotte's law.

In practice, the farad is too large a quantity, and the unit adopted is the microfarad, which equals $\frac{1}{1000000}$ farad.

We have, therefore, five electrical quantities and five corresponding units: (1) pressure, or electro-motive force, expressed in volts; (2) resistance of the conductors, in ohms; (3) flow, volume, or intensity of the current, in ampères; (4) quantity of electricity, in coulombs; (5) capacity of a condenser, in microfarads.

We can now enter upon an account of the electric batteries, confining ourselves to the newest systems which are most extensively used.

Classification of Batteries.—The batteries can be divided into several perfectly distinct groups, although there exists no absolutely rational and methodical classification—

1. From the nature of the soluble electrode; in practice, however, this character has no importance, for in almost all batteries zinc is used as the soluble electrode.

2. From the nature of the acting agent, which is sometimes an acid, generally sulphuric acid; acetic acid in Pulvermacher's battery; sometimes a salt like common salt, sal ammoniac, mercuric sulphate, lead sulphate, etc.

3. From the nature of the depolarizing agent, which can be copper sulphate, nitric acid, peroxide of lead, peroxide of manganese; in some cases the depolarizing and the acting agent form one single solution in the same liquid, as for instance in Grenet's battery, where zinc and carbon are immersed in a solution of potassic bichromate and sulphuric acid.

We shall therefore examine these batteries in groups of like nature, following the excellent classification of M. Alfred Niaudet, in his *Traité Élémentaire de la Pile Électrique.*

By sacrificing historical order, it will be easier to review the different apparatus producing an electric current by chemical action, and to dwell at greater length on those batteries which present a certain interest from the practical point of view, on account of their originality or their novelty.

Single-Liquid Batteries.

Since Volta's piles, a great number of single-liquid batteries have been constructed: the crown of cups or *couronne de tasses*, Cruikshank's battery, Wollaston's battery, the spiral battery, Muncke's battery, are only modifications of the fertile principle discovered by the Italian physicist.

These apparatus are very little used now in practice, on account of the rapid polarization of the elements. They are described in almost all treatises on physics.

In certain single-liquid batteries copper has been replaced by electrodes of other substances.

In 1849, Mr. Walker used carbon electrodes; others used iron as the unattacked electrode.

In 1840, Smee recommended platinized platinum to facilitate the generation of hydrogen bubbles. Walker replaced it, in 1857, by platinized carbon; in this form the single-liquid battery is still very much used for the railway service.

The negative electrode, or positive pole, in the single-liquid batteries is nowadays coated with substances which facilitate the generation of hydrogen or its combination with oxygen to form water.

In other single-liquid batteries the nature of the liquid has been varied. Hydrochloric acid has been used, but without success.

Nitric acid has also been used, but this is too expensive, and, like hydrochloric acid, gives off noxious vapours. Pulvermacher has used acetic acid to excite his galvanic chains, which are nowadays replaced by more perfect apparatus.

Independently of acid liquids, common salt has been

used; zinc-carbon batteries and common salt are extensively used in Switzerland for electric bells.

In his electric buoy Duchemin uses sea-water; in Bagration's battery sal ammoniac, in Stöhrer's battery a solution of alum is used.

Whatever may be the chosen liquid and electrode—and the number of these combinations is, so to speak, unlimited—it is very doubtful whether we shall ever again return to them, having at our command batteries with depolarizing mixtures, some of which we are going to describe.

Polarity of Batteries, Batteries with Two Liquids.—Let us take again our simple element, Fig. 1, which consists of a zinc plate, a copper plate, and water with sulphuric acid. If we close the current of this battery on a galvanometer, we produce a deflection of the galvanometer, which will gradually decrease till it becomes almost imperceptible under certain conditions. This decrease of intensity of the current, whatever may be the causes which produce it, is called polarization.

The polarization of the battery depends upon several phenomena, of which the following are the principal causes:—The impurity of the zinc, by creating small secondary couples in the midst of the zinc itself, is a cause which tends to diminish the electro-motive force of the couple. Mr. Kemp proposed in 1839 the use of amalgamated zinc to counteract this cause; and at the same time Mr. Grove read a paper before the Academy of Sciences to explain the importance of amalgamated zinc in batteries. Nowadays the zinc of all batteries is amalgamated. The weakening of the liquid by chemical action tends also to weaken the current, partly by the weakening of the chemical action,

partly by the increase of the resistance which the liquid opposes to the passage of the current.

The deposition of zinc on the copper by the current also tends to diminish its intensity, because the copper, coated with zinc, and acted on by the acid of the element, produces a new current in an inverse sense to the original current.

But the most powerful cause of polarization is the deposition of hydrogen on the copper.

The oxidation of the zinc and its transformation into zinc sulphate produce a certain quantity of hydrogen, which is deposited on the electro-negative plate (copper, platinum, or carbon). This deposition of gas on the copper plate opposes a material obstacle to the transmission of the current by the bubbles of gas. On the other hand, this hydrogen forms, with the oxygen given off at the other electrode, a sort of gas battery, and in consequence an electric flow in an inverse sense to the former. A theoretically perfect battery, in which we could do away with all these causes of polarization, would yield a constant current, and would really deserve the name of constant battery.

In practice this name is given to all those voltaic combinations which have for their aim the prevention or diminution of the deposition of hydrogen on the electro-negative plate. We shall see, on reviewing the batteries actually in use, the different ways in which this desideratum is more or less realized.

To continue our comparison between a battery, the focus of electricity, and a focus of heat, we say that polarization in a battery is a phenomenon analogous to the want of draught in a chimney. This want of draught produces a lowering of temperature, a decrease in the quantity of heat given off, and an imperfect utilization of

the fuel. In the battery these effects are shown by a diminution of electro-motive force, of the intensity of the current, and by the waste of zinc.

Theoretical Conditions of a Perfect Battery.—The following are, according to Mr. Fleming-Jenkin, the essential conditions which such a battery must fulfil :—

1. It must possess a great electro-motive force.
2. It must have a feeble and constant interior resistance.
3. Its electro-motive force must be constant, whatever the current produced may be with regard to intensity.
4. The materials used must be inexpensive.
5. The battery must not consume anything when it produces no current, that is, when the circuit is not closed.
6. It must be so arranged that we can easily verify its condition and working, and add fresh materials when required.

No known battery realizes all these conditions in the highest degree. The special exigencies in each case must determine the choice of a suitable element for the intended purpose. We will now examine by what proceedings these different conditions have been fulfilled, and describe in each group the principal types which practice has sanctioned.

Two-Liquid Battery with Copper Sulphate.—The use of copper sulphate or nitrate as a depolarizing agent was first recommended by Becquerel in 1829 after long and numerous experiments. The results obtained were very satisfactory, and he has always used these solutions.

It was not until 1836 that Daniell invented the battery which is called after him. Becquerel's and Daniell's batteries only differed in the nature of the porous cell, which was of gold-beater's skin in Daniell's, and of kaolin

in Becquerel's, for which have been substituted porous cells of pipe-clay.

The arrangement of the Daniell element is well known; we need not refer to it again. Its electro-motive force is, as we have seen, 1·079 volt, when the sulphuric acid is diluted with four times its weight of water; and its interior resistance varies, according to the size of the elements, their condition, etc., between one and twenty ohms.

The Daniell battery is constructed in many different styles; we know it in the form of flasks, as batteries with copper outside, and as trough batteries. Daniell's trough battery, constructed by Mr. Muirhead, is very much used, and the Post Office authorities have more than twenty thousand in use for telegraph service.

M. Carré has constructed a Daniell battery in which the porous cell was replaced by a cell of porous parchment paper, which considerably diminished the interior resistance of the battery, sixty elements of which were sufficient for the electric light. This is the first instance of the Daniell battery being employed for such a purpose, where a current of a certain intensity is required.

M. Minotto of Venice has invented a sand battery, which is very much used in Italy and in India. The separation of the two liquids arises from their different densities; zinc and copper are formed into two flat horizontal discs, the copper underneath. The copper sulphate is separated from the sand by a sheet of blotting paper or a piece of cloth. This battery offers a great interior resistance, but renders excellent service in telegraphy.

Trouvé's Moist Battery.—This is a Daniell battery, possessing the great advantage of acting without a liquid; the liquid used for the moistening of the elements can be poured out, or runs out of its own accord.

The elements of this battery are constructed in the following manner:—A round zinc disc Z (Fig. 2), and a copper disc C, are placed parallel to one another, and are separated by a pile of paper discs of a somewhat smaller diameter.

This mass of paper can absorb much water, and remains moist for a very long time, especially under conditions which we shall mention below.

The lower half of the paper discs is soaked in a solution of copper sulphate, the other half in a solution of zinc sulphate.

It will be seen that we have here all the constituents of an ordinary Daniell battery, in which the two liquids remain much more effectually separated than in porous cells.

The copper disc is supported in the centre by a rod isolated from the paper and zinc discs; it reaches beyond the slate fixed at the top of the element, which serves as a cover to the glass or ebonite vessel, in which the element is placed, to shelter it from currents of air, and from dust. The border of this vessel is rough, and the slate well adjusted; the element is thus contained in an hermetically closed space, and consequently preserved from evaporation.

Thus constructed the element acts for more than twelve months without requiring any looking after.

After a longer or shorter time, according to the amount of work done by the battery, the copper sulphate is reduced, and the battery ceases to act; it must then be recharged, which is an easy operation, only requiring a little care. It consists in dipping the lower part of the element into a hot solution saturated with copper sulphate. This solution is prepared in a copper basin made

for the purpose; it rises up to a certain level, and the cover of the element fits on to the edge of the basin, so that the paper is impregnated up to the desired height. As regards the zinc sulphate, it is constantly formed by the action of the battery, and therefore never needs to be replaced. The zinc itself is dissolved, and must be replaced after a certain interval; the paper is renewed at the same time. The copper on the contrary, when freed from the copper deposited on it in form of a powder by the action of

Fig. 2.—Trouvé's moist battery.

Fig. 3.—Trouvé's battery for military telegraphy.

the current, serves for an indefinite time, like the other parts of the battery.

The principal advantage of this new arrangement, invented by M. Trouvé, is the almost complete suppression of the interior work of the battery when the circuit is open. We may say of a Daniell battery which gives no current that it is a horse in the stable—which means, it consumes without producing; this is the only, but very grave objection to an ordinary Daniell battery.

This inconvenience does not exist, so to say, in Trouvé's moist battery, because there the liquids cannot easily mix owing to their different densities.

Callaud's Battery.—The method for the separation of the two liquids of the Daniell battery, by means of their different densities, was found simultaneously by Callaud in France, and Meidinger in Germany.

The Callaud battery has received several modifications in practice. We will describe here one of these modifications now very much in use.

Callaud's Battery, after Trouvé's Model.—This battery is very simple and inexpensive. It is chiefly used for therapeutic purposes, as it produces a continuous current. The

Fig. 4.—Callaud's battery, after Trouvé's model.

glass vessel is only twelve centimetres high, and seven centimetres wide. The zinc rests on the border of the vessel by means of three spouts, or folds, made with a pair of pincers (Fig. 4). A flat spiral of copper wire ends in a vertical piece rising in the centre of the vessel, which is protected by a small glass tube. The connection of the elements is effected by means of a small coil which terminates the

copper wire soldered to the zinc, and into which fits the copper wire, forming the rheophore of the following element.

Four Callaud-Trouvé elements, arranged in a little box, are sufficient to charge and keep charged the secondary batteries of M. Gaston Planté, of which we shall speak below.

Onimus' Battery.—Dr. Onimus' battery is another Daniell battery more especially arranged for medical application of continuous currents. It consists of an exterior glass vessel A, enclosing a small zinc cylinder Z (Fig. 5), and a copper rod *t* terminating in a copper plate *c*.

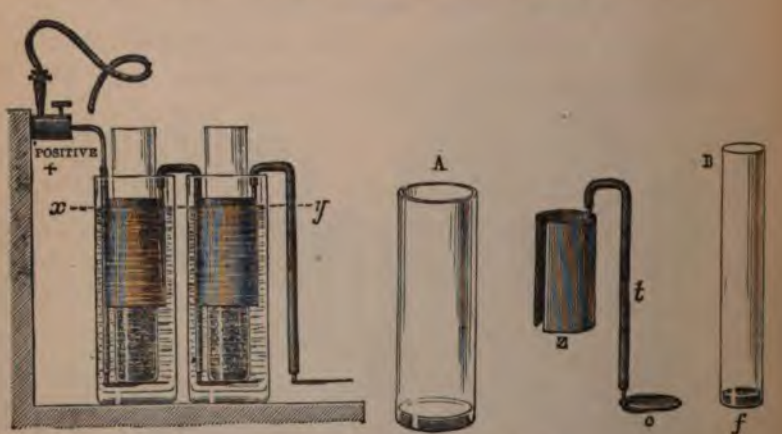


Fig. 5.—Dr. Onimus' battery: details of an element.

A glass tube B, open at both ends, is placed in the centre of the vessel, and closed at its lower extremity *f*, by gun-wadding calibre 24, which can easily be replaced if necessary. The tube B contains crystals of copper sulphate. The wadding acts the part of a porous cell. The battery is charged by pouring water into the vessel and the tube up to the height *x y*. A current is established after a few hours, and the battery works regularly for several months,

and only requires a few drops of water to be added at rare intervals and some sulphate crystals.

The advantages of this battery for medical purposes are its great constancy and feeble chemical action, for the solution of copper sulphate penetrates but little through the wadding.

No mixing of the liquids takes places during transport, and it suffices to remove the small tubes containing the crystals of copper sulphate, in order to arrest the action of the battery, for then the liquid sinks to a lower level, and the zincs are out of contact. On replacing the tubes in the vessels the battery acts as before.

Sir William Thomson's Battery.—This battery has a very large surface, and is composed of wooden troughs lined inside with lead. The copper plate is at the bottom; the zinc, in the form of a grating, rests on wooden brackets; the zinc and copper plates are thus close together. By placing seven or eight of these elements one above the other a powerful battery is obtained, applied by Sir William Thomson to the siphon recorder.

The electro-motive force of these elements without porous cells is somewhat superior to that of elements with porous cells, but it must be admitted that in practice they are nearly equal; the interior resistance does not exceed 0·2 ohm.

Sulphate Batteries.

Batteries have been constructed in which the copper sulphate and the copper plate are replaced by the plate of another metal and the corresponding sulphate; but these apparatus have on the whole no practical interest. The most important is Marié-Davy's mercuric sulphate battery. The copper sulphate is replaced by mercuric sulphate, and

the copper plate by a piece of carbon. The chemical action is analogous to that of the Daniell, except that the mercuric sulphate is nearly insoluble. Mercuric sulphate batteries have also been used without porous cells, and in Trouvé's reversible battery it is the solution of the mercury which forms at the same time the depolarizing and the acting agent.

Trouvé's Hermetical Mercuric Bisulphate Battery.—The battery, represented in natural size (Fig. 6), consists of a zinc-carbon couple, enclosed in an ebonite case of hardened indiarubber and hermetically closed. The zinc and the carbon only occupy the upper half of the case; the other half is occupied by the exciting fluid, which is a solution of mercurous sulphate.

Fig. 6.—Trouvé's hermetical battery.

As long as the case is kept vertical, with the zinc at the top, the couple will not plunge into the liquid, and no electricity is generated. On reversing the case the zinc and the carbon are immersed; a current is produced immediately, which ceases at once when the case is replaced in its former position. Hence the name of reversible battery. Trouvé has applied it to several induction apparatus, to his electric ...lorator, and to his little electric trinkets. (See Tissandier, *Récréation Scientifique*, Bibliothèque de *La Nature*.)

...ssrs. Gaiffe and Ruhmkorff also use mercuric sulphate

batteries with a single liquid to charge the induction coils of their small medical pocket apparatus.

Lead Sulphate Batteries.—Lead sulphate was used for the first time by Becquerel, then in 1860 by Marié-Davy, who gave to the element the form of a Daniell battery without Sir William Thomson's porous cell. Becquerel restored afterwards the ordinary Daniell form.

These batteries are no longer used now on account of the enormous interior resistance of the elements, which necessitates doubling their number in order to obtain the same intensity as the Daniell elements.

Acid Batteries.

The first battery with nitric acid as depolarizer dates from 1839, and was invented by the eminent physicist Grove. In Grove's battery the negative electrode, or positive pole, consists of platinum foil, which plunges into a porous cell, filled with concentrated nitric acid. Grove had proposed to replace the platinum by wood charcoal or graphitoidal charcoal deposited in gas retorts; but he did not follow up this idea, which was taken up again in 1843 by Bunsen, of Heidelberg.

All the Bunsen batteries constructed till 1849 were made with hollow carbon cylinders, placed with the acid in the exterior cylinder, and the zinc placed in the interior of the porous cell.

In 1849, Archereau first used prismatic carbon, which he placed in the porous cell, while he placed rolled zinc in the outside vessel. The battery which is universally known under the name of Bunsen battery, is therefore really the invention of Archereau.

The Bunsen battery has since undergone a number of

modifications which however have not succeeded in supplanting Archereau's original invention. Ruhmkorff however has constructed a Bunsen battery with flat elements, possessing two advantages—a small interior resistance, owing to the close neighbourhood and the large surface of the electrodes, and a small volume of nitric acid on account of the narrowness of the porous cell, where the carbon, in form of a thick prismatic piece, occupies about one-third of the space.

Tommasi has also modified Bunsen's battery with the idea of doing away with the nitrous vapours, and thus rendering the apparatus fit for domestic lighting. We are still waiting for the fulfilment of these handsome promises.

Chloric acid has also been tried as a depolarizer, as well as chromic and hydrochloric acids and aqua regia, etc.; but these batteries have not answered in practice, and have not reached beyond the state of laboratory experiments.

Oxide Batteries.

The depolarization in a battery being effected by the oxidation of hydrogen, this result can be obtained by using oxides which are easily decomposed.

De la Rive employed peroxide of lead and peroxide of manganese more than thirty years ago, but his batteries were never used in practice, and had been forgotten, when Leclanché invented the battery which bears his name, and which has been universally adopted.

Leclanché's Manganese Dioxide Battery.—An element of this battery is represented in Fig. 7. The exterior glass vessel is square: this form has the advantage over the round form of saving space when enclosed in a box, in other words, a less cumbrous battery is the result. This

vessel is provided with a neck of nearly the same diameter as the porous cell; so that the vessel is almost closed, and the possible evaporation of the liquid considerably diminished. This neck has a spout for the introduction or removal of the zinc and the emptying of the liquid contained in the vessel.

Fig. 7.—Leclanché's manganese dioxide battery.

The soluble electrode consists of a simple cylindrical rod of zinc, one centimetre in diameter; in the upper part of this zinc rod is a small central hole, into which is soldered a galvanized iron wire. This rheophore is at the same time flexible and solid; it can be formed into a spiral cylindrical coil, and is thereby rendered elastic, which is often desirable.

The porous cell has, as we have said, nearly the same

diameter as the neck of the exterior vessel; it contains about equal quantities of manganese dioxide and gas carbon. In the centre of this mass is a carbon plate, with a piece of lead at the top; a brass button is screwed into the lead, and is connected with the negative rheophore of the following element.

The outer vessel is half filled with a solution of ammonium chloride in water. The liquid penetrates after some time into the porous cell and the substances it contains.

The mixture of manganese dioxide and carbon is covered over with wax or melted resin to protect it in transport. A hole is made in this coating, through which the air can escape, when the water penetrates into the porous cell.

There is no chemical action in Leclanché's battery till the circuit is closed. Its electro-motive force varies between 1·4 and 1·5 volt. In the model of fourteen centimetres height the resistance varies between five and six ohms.

It contains no poisonous substances; gives off no acid vapours, no appreciable smell; the substances used are cheap, and resist the most intense cold. This battery is very much used in telegraphy, for electric bells, and in general domestic use. The depolarization obtained by the manganese dioxide is not complete, and with a short circuit the electro-motive force decreases rapidly. But it depolarizes very rapidly with the open circuit. In the case of intermittent service, as for instance electric bells and telegraphs, the polarization is imperceptible.

Leclanché has constructed a new battery, in which the porous cell is replaced by a mixture of forty parts of manganese dioxide, fifty-five of carbon, and five of gum-lac exposed to a pressure of three hundred atmospheres at 100° C. The contact of the zinc rod and the cylinder

is prevented by placing two very prominent indiarubber rings on the zinc rod.

For electric bells, Leclanché's batteries can be used four or five years without any other trouble than to add from time to time a little water in the outer vessel, to replace the water lost by evaporation.

Clamond and Gaiffe's Sesquioxide of Iron and Sal Ammoniac Battery.—This battery differs from Leclanché's only by the substitution of sesquioxide of iron for manganese dioxide. When the circuit is closed, the ammonium chloride attacks the zinc, and forms with it a double chloride of ammonium and zinc; the liberated ammonium acts upon the sesquioxide of iron, decomposes it, takes up part of its oxygen, and is given off as free ammonia.

Fig. 8.—Clamond and Gaiffe's battery.

This element, represented in Fig. 8, consists of a glass vessel, a porous carbon prism C, containing sesquioxide of iron in its pores, and a ring of amalgamated zinc Z. A cork, made of mastic, closes the vessel, and prevents the evaporation of the ammonium chloride solution.

The electro-motive force of the couple is 1·2 volt; it has the advantage of not being used up when the circuit is open. The depolarizing body can, during the time of rest,

take up the oxygen which it has lost during the time of action. Its action is unlimited, on condition that it is not overworked, and that the zinc and ammonium chloride are replaced from time to time. It can be used for medical batteries with a continuous current, for electric bells, and for house telegraphy, but from its enormous interior resistance it is but a feeble source of electricity. With larger dimensions it can be used for railway telegraphs and medical induction apparatus.

Chloride Batteries.

In these batteries the depolarization is effected by chlorine instead of oxygen.

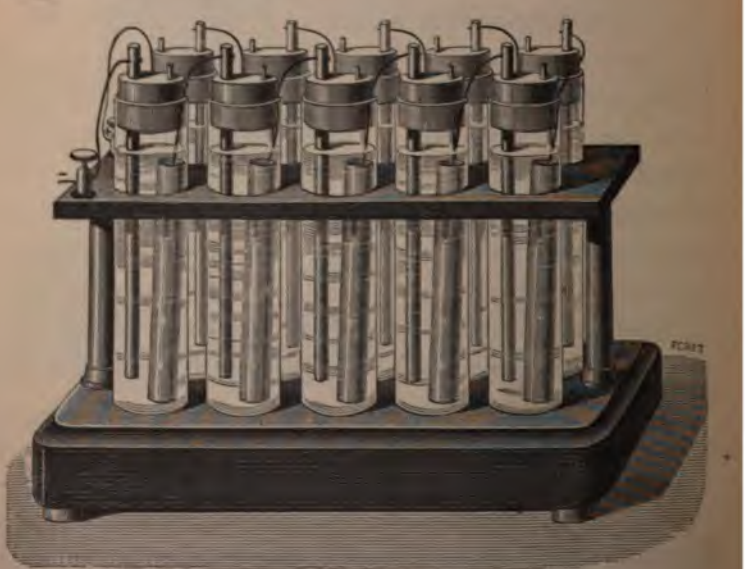


Fig. 9.—Warren de la Rue's battery.

We only mention Daniell's platinum chloride battery, which, of great value from a theoretical point of view, would be too expensive in practice.

Warren de la Rue's Silver Chloride Battery.—Marié-Davy was the first to use silver chloride as a depolarizing agent in 1860; but Warren de la Rue has used it in his battery since 1868, and the improvements effected by him are the result of his investigations on high-tension currents.

Fig. 9 represents the whole of a group of ten elements, mounted ready for action, and Fig. 10 the different parts constituting each element.

The outer vessel is a cylinder, thirteen centimetres long and three centimetres in diameter; the soluble electrode is a zinc rod not amalgamated (a rare exception from the general use of amalgamated zinc). Warren de la Rue employs, in preference, zinc from Vieille-Montagne, on account of its superior quality. A small silver strip, which forms the positive pole of the following element, fits into a hole made in the upper part of the zinc rod; the contact is assured by a small brass pin C, of slightly conical shape. The second electrode is formed by a silver ribbon surrounded by a cylinder of silver chloride. This silver chloride-stick is placed in a little cylinder of parchment paper A, to prevent accidental contacts.

The liquid is a solution of twenty-three grammes of ammonium chloride in one litre of water. The outer vessel is closed by a paraffin cork, one of the best insulators known, and which, in virtue of its anti-hygrometric properties, prevents the water which might be spilled on its surface, from spreading, and thus causing a deviation of the current.

The action is very simple: The zinc dissolves, and replaces the silver in the chloride; the silver resulting from the decomposition is deposited in the form of a porous substance, first on the surface, and then gradually in the mass of the silver chloride. This battery gives rise to no

local action, as long as the exterior circuit is not closed. This is very important in experiments of short duration, repeated at long intervals. Although this is a single-liquid battery, it must be remarked that the acting agent, chloride of silver, is a solid body, which is not dissolved in the liquid in contact with it, but supplies the chlorine necessary for the solution of the zinc.

The electro-motive force varies between 1 and 1·07 volt; its interior resistance depends upon the time of action and the dimensions of the element. In the model which we have just described, the resistance varies from 2·7 to 4·3 ohms. Warren de la Rue has 11,000 elements of this battery, which enable him to make the most interesting experiments on the electric spark, the description of which, however, does not come within our scope.

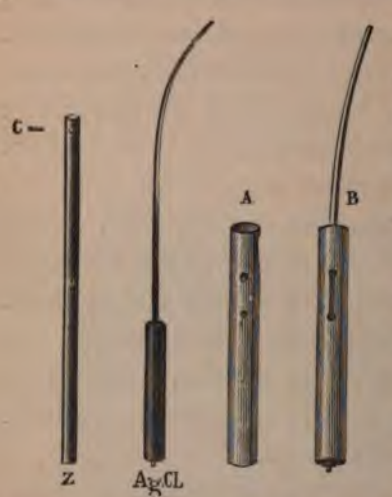


Fig. 10.—Details of an element of Warren de la Rue's battery.

Gaiffe also uses the silver chloride battery for continuous currents and for medical induction apparatus. These elements are of very small dimensions, and are kept in hermetically closed ebonite boxes, with covers to screw on.

Duchemin proposed, in 1866, the use of iron perchloride as depolarizer, but there is only an incomplete depolarization effected in the element, and the zinc is soon covered with non-conducting deposits.

Marié-Davy has tried lead chloride, but the electromotive force of this element is feeble, and lead chloride is rather expensive; the battery has, therefore, no special advantage.

Niaudet's Battery with Bleaching Powder.—In Niaudet's battery, represented in Fig. 11, the zinc is immersed in a solution of sodium chloride, and the carbon in a solution of bleaching powder, which acts here the part of depolarizer.

Fig. 11.—Niaudet's bleaching powder battery.

The bleaching powder of commerce, used as bleaching agent and disinfectant, is a mixture of lime, calcium hypochlorite, and calcium chloride. The hypochlorous acid which it contains is composed of oxygen and chlorine, which can both unite with hydrogen to form water and hydrochloric acid. This latter acts upon the lime, and produces calcium chloride. The substances formed being all soluble, the liquid remains clear. When the circuit is open, the zinc is not acted on; there is, therefore, no waste.

The electro-motive force of this element is 1·6 volt. The bleaching powder possessing a very disagreeable smell, the vessel containing the battery must be closed by means of a cork coated with wax. The zinc, with its bent end-piece, is kept at a regular, very short distance from the porous cell by means of small wooden sticks, squeezed between the zinc and the cell by two springs. By this arrangement the zinc does not descend to the bottom of the liquid, and the formation of local couples is avoided, which would result in mere waste.

Batteries with Depolarizing Mixtures.

We have examined in the preceding pages batteries in which the electro-negative electrode (copper, platinum, carbon, or silver) is surrounded by substances easily giving off oxygen or chlorine, which combine with the generated hydrogen, and produce partial or total depolarization. Another method consists in surrounding this electrode by two substances which, by their reaction upon one another, produce either oxygen or chlorine.

The batteries of this kind which are most extensively used are potassic bichromate batteries.

Poggendorff was the first to use a mixture of potassic bichromate and sulphuric acid for depolarizing the conducting electrode.

Since then the bichromate battery has been improved in various ways, and has become very convenient and very practical.

The electro-motive force of the elements reaches two volts; it is greater than that of the Bunsen and Grove elements, but, in spite of the mixture, a rapid polarization is produced, especially when the exterior circuit has little resistance.

Complicated reactions ensue in these elements, tending to the formation of chrome alum, which, by its formation, produces a current in the opposite direction of the element; the result is an energetic polarization and a rapid exhaustion of the liquid.

Grenet's Battery.—In 1856, Grenet had established a system of ventilation in the interior of the liquid which prevented the deposition of chrome alum, and destroyed, by the action of the air on the nascent hydrogen, the polarization which might have ensued.

In practice nothing could be expected of so complicated a system, and the battery which now bears the name of Grenet is nothing else but the well-known flask or bottle battery, which renders such good service for experiments of short duration.

Potassic Bichromate Battery, with Windlass-Stand.—This battery gives a powerful current, without smell, provided it is only used for a short time, and that the zincs are taken out of the liquid after each experiment.

Ducretet has constructed a model composed of bichromate elements, suspended by cords, wound up by a ratchet-wheel A r (Fig. 12). Each element consists of a large amalgamated zinc plate Z, placed between two carbons C C′, and insulated by a block of ebonite E; a brass hook S fixes this plate, and serves at the same time as conductor, and as hook for the cord of the stand. The carbons are screwed on a metallic square P, a metal post with binding-screw being fixed on this square for the conducting wire. The best solution consists of—

Potassic bichromate	200 grammes.
Water	2 litres.
Common sulphuric acid	150 to 200 grammes.

It is advisable to add five grammes of mercuric bisulphate to keep the zincs well amalgamated.

Gaiffe has constructed a similar battery, with stand, in

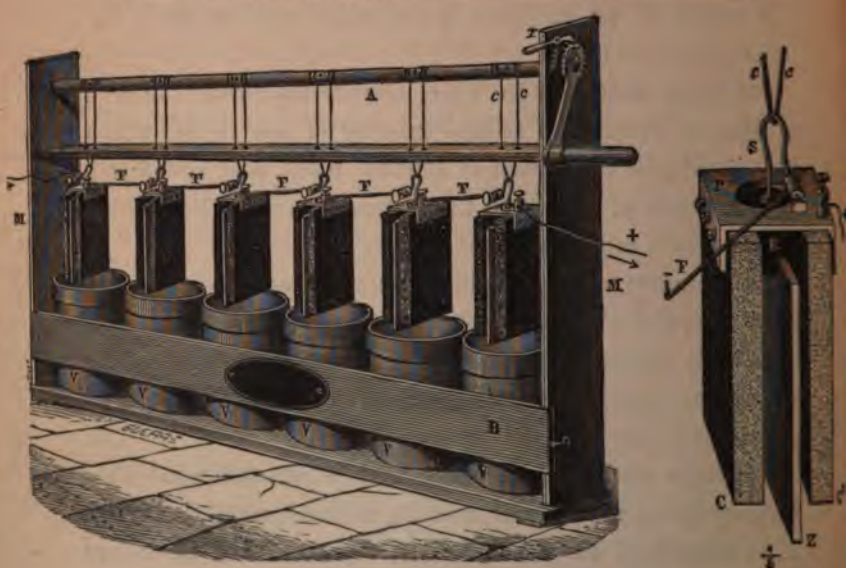


Fig. 12.—Bichromate battery, with windlass-stand.

which the carbons and zincs are permanently fixed to a cross-bar, which prevents the elements from swaying to and fro when they are raised, and also the acid liquid from being thrown out.

Trouvé has constructed another model, in which the elements can easily be taken to pieces and cleaned, the zincs amalgamated anew, and replaced if necessary.

Camacho arranges the elements one above the other, and causes the depolarizing mixture to circulate; this produces a certain motion favourable to depolarization. The carbon electrode is placed in a porous vessel filled with fragments of gas carbon; an enormous surface is thereby given to the electrode, which renders polarization very slow.

Cloris Baudet has also constructed a battery to which he gave the somewhat pretentious name of "Impolarisable" (not capable of polarization), and in which the porous vessel, containing the zinc, has two small vessels soldered to it sideways: one of these small vessels contains sulphuric acid, the other, which is pierced with holes, contains potassic bichromate. Thus a stock of materials is provided which fairly maintains the solution in a state of sufficient concentration, but this does not explain how polarization is prevented.

Fuller has invented a bichromate battery, used in America and in England for telegraphy, where the zinc, placed in the centre of the porous vessel, plunges into mercury, which preserves its amalgamation.

Use of Batteries in Electric Appliances. Available Maximum Work.—In all the batteries which we have described we invariably find zinc as the fuel. The available work in the exterior circuit of a battery depends therefore on the number of calories produced by the combination of zinc with the acting agent. Looking at it from this point of view, the battery which renders valuable service in telegraphy, for electric bells, medical apparatus, laboratory experiments, etc., is absolutely unable to supply large quantities of electricity. Zinc is an expensive fuel; an equal weight of zinc costs fifteen times as much as coal, and generates five times less heat. This fact alone sufficiently explains why batteries are seldom, if ever, used for electric lighting, and also the numerous researches made nowadays on thermo-electricity and electro-dynamic machines.

We prefer the use of machines for this purpose, as well as for galvano-plastic and many other appliances, in spite of their being more complicated.

We reserve the battery for work where electricity is required, more for the rapidity and delicacy of its action, than for its efficiency. We shall see its remarkable application for the telegraph and the telephone. For electric lighting and for electro-motors, where calories and work are required, the batteries labour under the disadvantage of burning a too expensive fuel—zinc, and also of burning it too slowly; which necessitates the use of a considerable number of elements, without yielding the corresponding available maximum work.

Unless a complete revolution in the production of electricity by direct chemical action takes place, the principles with which we are acquainted now do not permit of the construction of a battery, at the same time powerful and economical, for applications which require these two qualities united to a very high degree.

CHAPTER II.

THERMO-ELECTRIC BATTERIES.

THERMO-ELECTRIC batteries are apparatus which transform heat into electricity. The discovery of this highly important fact was made in 1821, by Professor Seebeck, of Berlin. On soldering to a plate of bismuth the ends of a copper plate,

Fig. 13.—Seebeck's experiment.

bent in such a manner as to leave an empty space between the two plates, Seebeck found that on heating one of the solderings of this metallic couple, a magnetic needle, placed between the two plates, was deflected, the current passing always from the hot to the cold soldering of the copper, and from the cold to the hot soldering of the bismuth.

Becquerel attributes the production of the current to the unequal propagation of heat in different parts of the heterogeneous circuit caused by the two different metals.

Whatever may be the metals entering into the composition of the thermo-electric couples, they are easily distinguished from the hydro-electric couples by the nature of the currents. In a battery, in fact, each couple or element possesses a strong tension, varying from one to two volts, and a rather considerable interior resistance (varying from 0·2 to 15 and 20 ohms); in the thermo-electric couple, on the contrary, for a difference of temperature of 100° between the solderings, the electro-motive force, very variable with the nature of the constituting elements and the mean temperature of the two solderings, varies between $\frac{1}{10}$ and $\frac{1}{100}$ volt, whilst the interior resistance is very weak. We express this fact by saying that thermo-electric batteries give quantity, but little tension; a large number of them must therefore be joined to obtain a certain electro-motive force. We shall give some figures with regard to the different elements which we are going to describe.

Becquerel, by making experiments between 0° and 20° with different metals, has been able to classify them in such order that each of them is negative with regard to the preceding ones, and positive with regard to those which follow.

The following is the order of the metals experimented on by Becquerel:—

Bismuth, platinum, silver, tin, lead, copper, gold, zinc, iron, antimony. It would seem, *a priori*, that on taking the most remote elements of the series for the formation of a couple, the largest electro-motive force would be obtained for a given difference of temperature. Other considerations

of a theoretical and practical nature show that such is not the case.

Practice suggests the choice of metals, of alloys, or substances in which the difference of temperature of the solderings can be maintained at the highest possible degree without altering the battery. The nature of the metals used naturally influences the cost of the battery.

The law, stating that the electro-motive force of thermo-electric currents is proportional to the difference of temperature, is only correct with special reservations as to the mean temperature of the two solderings, and to the neutral point which varies with the nature of the metals employed. An example will show better than any theoretical explanation, what we mean by the neutral point of a thermo-electric couple. Let us take, for example, a thermo-electric couple formed of the two metals copper and iron. Let us suppose the cold soldering of the couple to be at 70°, and the hot soldering at 450°. No current will pass through the couple thus constituted, although the difference of temperature is 380°. The reason is that the neutral point of iron with regard to copper is 210°, that is to say, that at 210° the thermo-electric current formed by the two metals changes its direction, and as the mean temperature between the two solderings is precisely equal to 210°, two currents of equal tension, but different directions, are produced which destroy each other.

While maintaining, therefore, a great difference of temperature between the two solderings of a thermo-electric couple, we must take care that the temperatures are not, the one higher, and the other lower, than the neutral point of the two metals forming the couple, for we should then obtain only a differential current, liable to become null

when the mean temperature of the two solderings corresponds to the neutral point.[1]

If the difference of temperature in a thermo-electric couple is constant, the current itself is constant, for no polarization or variation is produced in the resistance of the couple. The electro-motive force of a thermo-electric battery is proportional to the number of elements constituting the same, exactly as is the case in hydro-electric batteries.

These principles being established, we will pass in review the different thermo-electric couples used in practice.

Œrsted and Fourier have constructed the first thermo-electric battery. It was composed of small bars of bismuth and antimony soldered together in regular order, and in a straight line. The bars of bismuth terminated in a soldered piece which plunged into ice at zero, whilst the other solderings were heated from 200° to 800° by small lamps.

Nobili has simplified Fourier's battery by bending the bars in zigzag; he has thereby enclosed fifty elements in a cube, the sides of which were two centimetres long. Melloni has used this cube in his thermo-multiplier.

Marcus' Battery.—In this battery alloys are used instead of simple metals. One of these alloys consists of nickel, copper, and zinc, known as German silver; the other of antimony, zinc, and bismuth. The solderings are heated by a small Bunsen burner. Wheatstone and Ladd have each constructed a battery with the alloys recommended by Marcus; the former obtained sparks with this battery, as well as the incandescence of a platinum wire, and the decomposition of water in a voltameter; the latter set in action a Ruhmkorff coil which gave a spark of thirty-eight millimetres.

[1] See, for further details, *Electricity and Magnetism*, by Fleming-Jenkin; and *Philosophical Transactions*, 1856, p. 708.

Farmer's Battery.—Farmer, of Boston, constructed in 1868 a similar battery to that of Marcus; its positive plates consisted of ten parts of copper, six of zinc, and six of nickel, and the negative plates of twelve parts of antimony, five of zinc, and one of bismuth; the two metallic plates were screwed into each other, the lower joints heated by a gas flame, and the upper joints cooled by a stream of water.

Becquerel's Battery.—In 1865, Becquerel, in his researches on the thermo-electric force of artificial copper sulphide, found that this substance, heated to 200° or 300°, is strongly positive; its point of fusion is above 1000°, and it can therefore be used at very high temperatures. The metal which Becquerel associated with it was German silver (ninety of copper and ten of nickel); the battery is heated with gas, and cooled by a stream of water.[1]

None of these batteries have been used in practice; they are only fit for laboratory experiments.

We are now going to describe some batteries which have found more or less numerous applications for galvano-plastic, and latterly for electric lighting.

Noë's Thermo-Electric Battery.—This battery is extensively used in Austria and Germany. Under the form represented in Fig. 14, only two Bunsen burners are required to set in action forty elements, three for sixty, and so forth, one for each group of twenty, according to the intended application.

The elements in each group are placed horizontally, like the radii of a circle, the hot solderings in the centre, the cold solderings in the circumference.

The two metals used are German silver and an alloy

[1] See the description and diagrams in Ganot's *Physics*, translated by Atkinson, 3rd edit., p. 787.

of antimony and zinc, and are soldered together without the use of an intermediate metal. The extremities of the German silver wires reach into a brass capsule, which forms the bottom of the mould in which the other metal is cast. Fig. 15 represents two separate elements in natural size; the small capsule *c* is attached to the element, and forms part of the apparatus. Into this same capsule

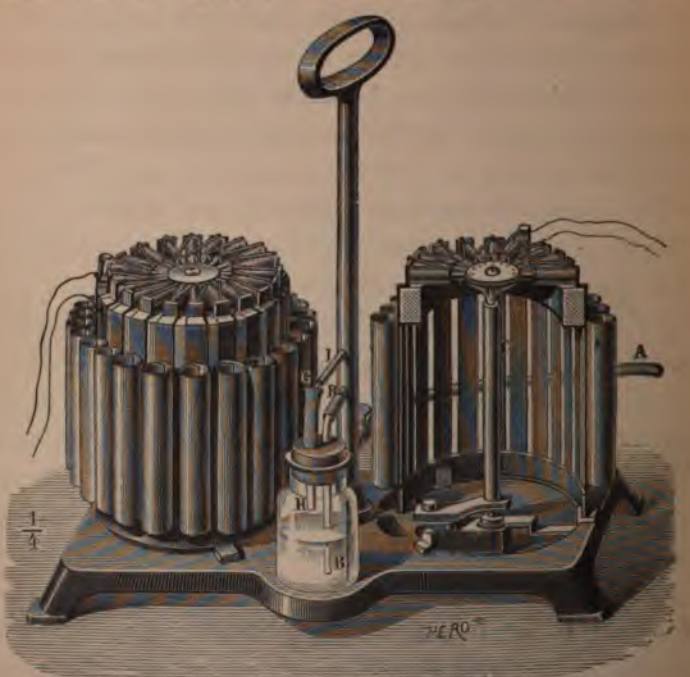


Fig. 14.—Noë's thermo-electric battery.

reaches a small copper rod *r*, whose extremity is likewise held fast by the molten metal, and which conducts the heat to the hot soldering. The extremities of these copper rods form a small circle, fastened between two mica plates, and are all heated simultaneously by a single flame, generally a Bunsen burner; a spirit lamp is sometimes used.

By heating the solderings by conduction, they are protected against overheating, which would fuse the metal and render the battery useless. The loss of heat by radiation is prevented by covering the rods with small insulating tubes *t* (Fig. 15).

For the cold soldering the fusible metal is soldered to a copper plate, to which are also soldered the "maillechort" (an alloy of copper, nickel, and zinc) wires of the next element; the copper plate, of cylindrical form, presents a large surface for radiation favourable to its cooling, which is besides accelerated by the circulation of air inside the copper tubes.

Under the most favourable conditions, that is, by heating the solderings to nearly their point of fusion, the Noë elements, according to Waltenhofen's experiments, have an electro-motive force between $\frac{1}{9}$ and $\frac{1}{10}$ volt; whilst the Marcus elements have only an electro-motive force of $\frac{1}{18}$ volt.

Fig. 15.—Details of an element of Noë's thermo-electric battery.

In practice, however, these figures are not reached, for all the elements cannot be equally heated, and we can only reckon upon $\frac{1}{15}$ volt per element; under these conditions the interior resistance is $\frac{1}{40}$ ohm.

Each group of twenty elements has, therefore, an electro-motive force of 1·25 volt, and an interior resistance of 0·5 ohm.

We have to mention here a very practical regulator for the pressure of the gas, which prevents the overheating of the battery, and the accidents which might arise from it.

This safety apparatus consists of a glass bottle (Fig. 14), containing water, and closed by a cork. Two tubes pass

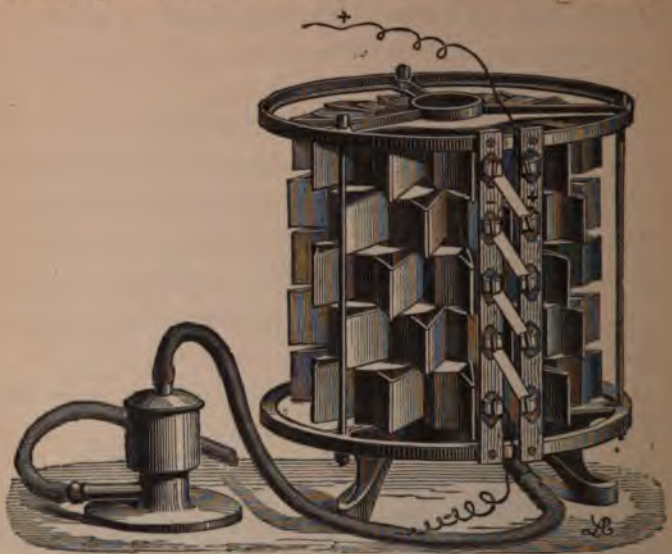


Fig. 16.—Clamond's thermo-electric battery, heated with gas.

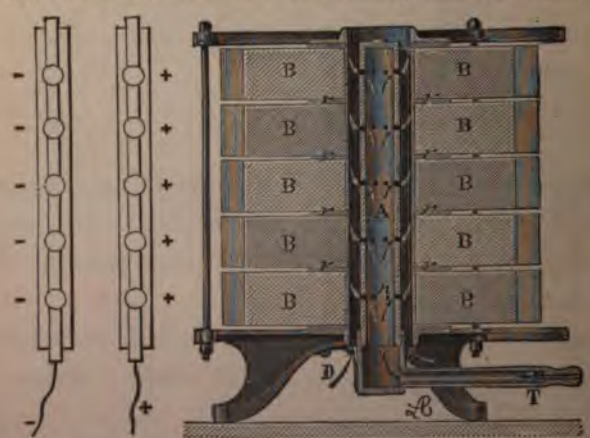


Fig. 17.—Clamond's thermo-electric battery (vertical section). T, gas supply tube; A, perforated earthenware tube, where the gas is mixed with air, the mixture passing into the outside cylinder, where it is burned; B B, thermo-electric bars; D, entrance of air for combustion; r r, discs of asbestos for the insulation of the elements.

through this cork: the one B R is a branch tube of the gas-supplying tube, and reaches to the bottom of the bottle; the other, H, only reaches to the level of the water—it carries off the gas which may be collected in the bottle, and leads it before another branch tube, terminating in a burner I, which is kept constantly burning. In case of an excess of pressure, the gas rises in bubbles through the water, escapes at G, and is burned, without producing any accident or any bad smell.

The bottle acts thus like a real safety-valve. Twenty elements suffice for the decomposition of water, and forty to charge Gaston Planté's secondary battery, and to set an induction coil in action.

Two minutes are sufficient to generate a current, and the action can be stopped at any moment.

This battery suffers no alteration in the course of time like the other batteries described in the preceding pages, and in which continuous heating would produce a considerable increase of interior resistance, and, in consequence, a corresponding weakening of the outer current.

Mure and Clamond's Battery.—The first battery constructed by Clamond, in co-operation with Mure, was shown to the Institute by Becquerel, on the 31st of May, 1869. It consisted of galena and leaden plates.

The intensity of this battery is diminished by use, for the interior resistance increases, in consequence of the oxidation of those places of contact where the iron plates touch the crystallized bar, and also from the splitting of the bar after axes perpendicular to its length.

Clamond's Battery.—On the 20th of April, 1874, Jamin exhibited before the Académie des Sciences a new battery by Clamond, heated with gas, in which these drawbacks

are avoided. Clamond has adopted, for the construction of his couples, Marcus' alloy of zinc and antimony, which is a good conductor of electricity, and which can easily be

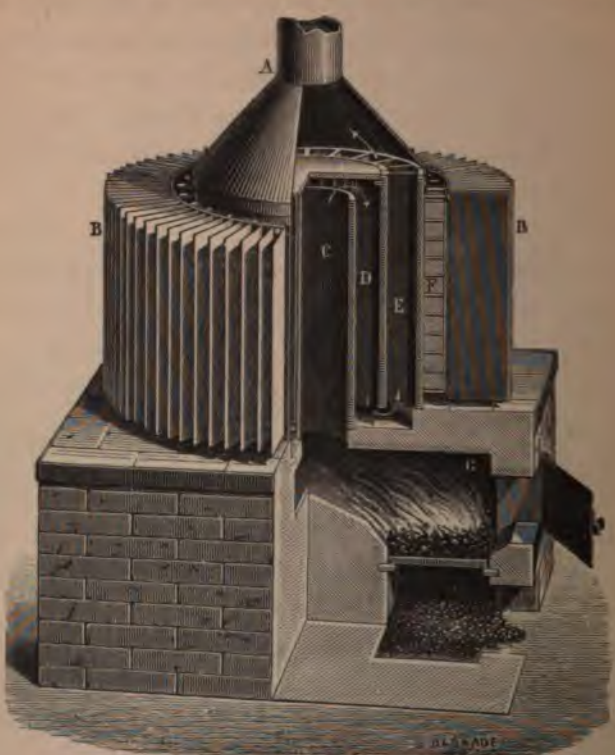


Fig. 18.—Clamond's thermo-electric battery, heated with coke.

manufactured by casting. The armature consists of iron plates, in preference to copper and German silver, because the iron resists very well, whilst the two metals named are acted upon and dissolved, and soon become useless.

The bars are arranged in form of a star, and coupled for tension.

These stars placed one above another, of ten elements

each, are separated by asbestos discs. The whole apparatus forms a cylinder, lined inside with asbestos (Fig. 16), and heated with gas by means of a perforated earthenware tube. The gas, mixed with air, passes through this tube, and burns in the annular space between the tube and the bars. The extremities of these stars fit into copper clamps, fixed on two small planks, which permits the coupling together of the stars of ten elements, either for tension or for quantity.

The gas supply is regulated by Giroud's rheometer. Figs. 16, 17, and 19 represent the exterior view, the vertical and horizontal sections of Clamond's battery. The explanations accompanying the sections will suffice to explain the arrangement of the battery. This apparatus of fifty elements consumes five centimes' worth of gas per hour, and can deposit twenty grammes of copper per hour. It is used in the printing department of the Bank of France, and in the photographic studios of Messrs. Goupil and Co. at Asnières.

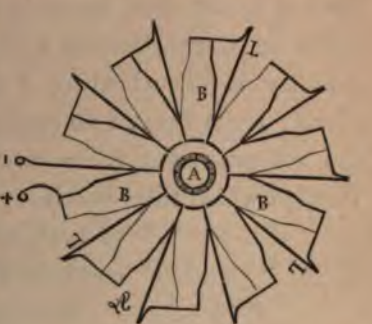


Fig. 19.—Clamond's thermo-electric battery. Horizontal section of the bars and their armatures; B B, thermo-electric bars; L L, plates forming the armatures.

Clamond's Battery heated with Coke.—Since 1874, Clamond has continued his researches on thermo-electric batteries, and on the 5th of May, 1879, Count du Moncel submitted to the Académie des Sciences a new battery, much more powerful than the former ones, which can be used for electric lighting.

Fig. 18 (p. 46) represents a view of Clamond's new battery; Figs. 20, 21, and 22 give the principal details.

The apparatus consists of three parts—

1. The furnace and the collector, for heating the interior solderings of the battery.

2. The battery itself, arranged in form of a star.

3. The diffusor, for cooling the exterior solderings.

Furnace and Collector.—The battery is heated with coal or coke. The gases, produced by combustion, pass from the furnace G (Fig. 18), through the cylindrical cast-iron pipe C, downwards through a series of compartments D arranged in form of a star, then upwards again at E, through a second series of compartments, and finally escape through the chimney A. The heating of the elements, therefore, is not *direct;* there is even no contact between the elements and the hot gases, but these gases heat the mass of cast iron through which they circulate; this mass acts as a *collector* of heat, which it gives off to the elements in a more uniform manner.

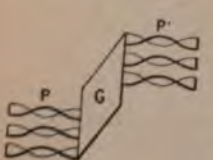


Fig. 20.—Armature of an element of Clamond's battery.

Battery.—The battery consists of a series of *chains* arranged in form of a crown around the collector, and heated on the inside. The battery of three thousand couples consists of sixty chains of fifty couples each.

Each couple consists of a thermo-electric bar, three centimetres long and wide, and two centimetres thick. These little prisms are formed of an alloy of antimony, and joined together by iron armatures (Fig. 20). These armatures are cut into thin sheets, twisted like corkscrews at their extremities P and P'. To make a chain, these armatures are placed in a special mould, after having

surrounded the flat part G with a coating of asbestos, and the alloy is cast in the mould. The fifty elements are thus made at once, the parts P and P′ of each armature are joined to two successive couples by a soldering made of the same material as itself. The chains are arranged vertically and in form of a star, between the collector A and the diffusor B (Fig. 22), by placing between them and the chains thin laminæ of mica, which insulate them, while they allow the circulation of heat. In a battery of 6000 elements, two groups, of 3000 elements each, are arranged for tension. For a temperature of 360° in the

Fig. 21.—Thermo-electric chain of ten elements.

heated, and of 80° in the cooled solderings, three thousand elements represent, according to experiments made by G. Cabanellas, an electro-motive force of 109 volts, and an interior resistance of 15·5 ohms.

Diffusor.—The diffusor maintains the exterior solderings of the chains at the lowest possible temperature, which, in practice, does not exceed 80°. It consists of a series of copper plates, placed all round the battery, and which increase the surface of cooling. These plates are represented in B (Fig. 22). Clamond's coke battery is therefore, in fact, an electrical heat-engine, and can be used in all cases as such. An apparatus of 6000 elements consumes from nine to ten kilogrammes of coke per hour. With an arrangement of two circuits of 3000 elements each, two Serrin lamps can be fed, giving a light of from thirty to fifty gas-burners each (equal to 450–750 candles).

We have here two remarkable results, worthy to be followed up, and we regret that the experiments, commenced in 1879, have not been continued. Although hitherto the efficiency of the thermo-electric batteries, that is, the proportion of the heat consumed to the heat changed into electricity, is very slight (it does not exceed four to five per cent.), these apparatus are interesting, for they transform, in a direct manner, heat into electricity, whilst the electro-dynamic machines, which we are now going to describe, pass through complicated intermediate stages. It is always easier to keep up an electrical heat-engine or to feed a gas battery, than to pass through the intermediate stages of a motor or a dynamo-electric machine. We shall have occasion to mention this question again, with reference to electric lighting and its prospects.

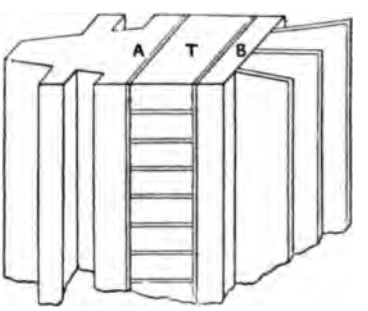


Fig. 22.—Clamond's battery. A, collector; T, thermo-electric chain; B, diffusor.

We have to mention here another application of the thermo-electric battery, made by Gaugain for the purpose of telegraphing. He uses bismuth-copper couples, arranged in horse-shoe form alongside of each other on a cross-beam of wood, which allows of their being raised or lowered at once into two liquids, one of which is distilled water at 0°, and the other heated paraffin at 100°. This battery has a constant electro-motive force, and is therefore an excellent standard battery. Its electro-motive force is $\frac{1}{182}$ volt; by arranging, therefore, 182 elements for tension, and keeping the solderings exactly at 0° and 100°, we have a battery with an electro-motive force of exactly one volt.

Contrary to all expectation, no progress has been made, within the last twelve months, in the practical application of thermo-electric apparatus, and, with the exception of some applications to galvano-plastic, made by the Bank of France and by Messrs. Goupil, of Paris, these apparatus only present a scientific interest. Even the recent Paris Electrical Exhibition, which marks a new era in the practical application of electricity, showed no advance in this direction.

CHAPTER III.

ELECTRO-DYNAMIC MACHINES.

THE transformation of work into electricity is the most complicated means for producing an electric current, and yet it is, up to the present, the most economical and the most extensively used in all applications which require powerful currents. This extensive employment of machines is of comparatively recent date, although the discovery of the fundamental principle of all machines was made by Faraday in 1830.

The way to this discovery had been prepared by Œrsted's experiments, made as early as 1820, on the action of a current on the magnetic needle, and by Arago's discovery, made shortly afterwards, of the magnetization produced by a current. The action of electric currents on magnets, and their magnetizing action on soft iron, being known since 1820, it seems but natural to draw an *a priori* conclusion that an inverse action must take place when a permanent magnet acts on a closed spiral circuit; but ten years elapsed before Faraday observed this phenomenon and investigated its different bearings.

We need not enter here upon the theory of induction currents produced by the approach or withdrawal of a magnet or current; the laws of these currents, as stated by

Lenz and Matteucci, are to be found in any text-book on physics.

All electro-dynamic machines are founded on Faraday's discovery, and the laws of Lenz and Matteucci, applied to practical methods for the most effective collection of induction currents.

Classification of Electro-Dynamic Machines.—We have no general term for designating the whole of the machines which transform work into electricity. We have chosen that of electro-dynamic machines, however, not to be confounded with dynamo-electric machines, because this term signifies at the same time the cause which is work, the force (*δύναμις*), and the effect which is electricity engendered by this work.

Every electro-dynamic machine — the term electro-dynamic to be taken in the sense mentioned—consists of two fundamental, necessary, indispensable parts: the inductor and the armature. By moving the inductor before the armature or, as a general rule, the armature before the inductor, electric currents are produced in the wire of the armature, whose nature, intensity, and sense are defined by Lenz's laws. These laws show that, in order to obtain powerful currents, the armature must be moved with great speed before powerful inductors.

Any mechanical arrangement which enables us to obtain this result is an electro-dynamic machine.

The function of the inductor is to create a special condition of movement of the surrounding ether, and this is called the magnetic field. This magnetic field can be produced by two very different methods, and, according to these methods, electro-dynamic machines can be divided into two classes.

If the magnetic field of the inductor in which the armature moves is produced by a fixed and permanent magnet, the machine is called magneto-electric.

If the magnetic field is formed by an electro-magnet, whereby its intensity is increased—electro-magnets being, for equal weight, much more powerful than permanent magnets—the machine is called dynamo-electric. This name, although rather inappropriate, since it recalls but very indirectly the means by which the magnetic field is constituted, is nevertheless universally adopted by usage, and must be retained in this book.

The above division is based on the nature of the inductor; there is a second one, more important still, based on the nature of the currents collected outside the machine on the external circuit. According to Lenz's laws, when an element of the spiral wire of an armature traverses a magnetic field, the current engendered in this element circulates now in one sense and then in another;—this is an alternating current.

When the machine directly collects the alternating currents thus produced, without reversing them, that is to say, if the currents pass into the outer circuit without changing their sense, the machine is an alternating-current machine.

If, on the contrary, the machine reverses the alternating currents, which then circulate always in the same sense in the external circuit, it is a continuous-current machine.

We shall only describe those types of machines which are the most extensively used—

A.—Machines with Continuous Currents ... { *a.—Magneto-electric.* / *b.—Dynamo-electric.*

B.—Machines with Alternating Currents... { *a.—Magneto-electric.* / *b.—Dynamo-electric.*

A.—Machines with Continuous Currents.

a.—Magneto-Electric Machines.

Although the discovery of induction was made by Faraday, in 1830, the electric spark by induction was only obtained on the 31st of January, 1832, by Nobili, in Florence; but even in his case there was no current in the proper sense of the word.

The first machine which gave a current was constructed by Hippolyte Pixii, of Paris, and was brought before the Académie des Sciences on the 3rd of September, 1832.

Pixii's Machines.—We only mention this historical machine to point out a rather curious peculiarity which is not to be found in any other magneto-electric machine. The well-known apparatus consists of two coils and a horse-shoe magnet, whose poles are placed to face the coils, and turn in such a manner as to present their two poles successively before the extremities of the coil.

Instead of moving the inductor in the magnetic field, the magnetic field is moved before the inductor; but this arrangement does not in any way affect the principle. The currents thus developed are alternating, but by means of a commutator invented by Clarke, the currents were reversed, and Pixii's machine was the first with continuous currents. The first improvement in this machine was effected by Saxton.

Saxton's Machine.—This machine is arranged like Pixii's, that is to say, the magnet and the coils are placed end to end, but the magnets are fixed, and the coils are movable. Consequently, as there is a smaller mass to be moved, the machine need not be so heavy for equal power.

Clarke's Machine.—In 1834, Clarke constructed a machine in which the magnet was vertical and the coils horizontal; they presented themselves, therefore, to the inductor, no longer by their ends, but by the flat sides of the horse-shoe magnet. In this form, magneto-electric machines have been introduced into all physical laboratories, and are still so used in medicine.

Clarke's Machine after Gaiffe's Model.— A, B, B′ (Fig. 23), is an electro-magnet; H, one of the coils of the soft-iron

Fig. 23.—Clarke's machine after Gaiffe's model.

armature turning before the arms of the magnet; R is the toothed wheel, and M the winch-handle, which communicate the rotatory motion to the coils. The whole apparatus,

with the hand-pieces, the crank, and all accessories, can be enclosed in a small box.

The power of the currents can be varied by increasing the speed of rotation, and by arming the magnet, which under these conditions gives a less powerful current.

Page's Machine.—In 1835, Page, an American, constructed a machine, in which the fixed coils surrounded the magnet, which was fixed likewise. The currents, produced by the rapid rotation of a soft-iron armature before the extremities of the magnet, were alternating, in consequence of the successive overcharging and weakening of the magnetic field; these currents were afterwards reversed in the ordinary manner by a Clarke's commutator.

All these machines and several others based on the same principle, were only apparatus of feeble power, and found but a very limited application. In 1849, Nollet, Professor of Physics at the École Militaire, Brussels, constructed a Clarke's machine on a large scale, and that machine is now called the Alliance machine.

Nollet's apparatus gave no favourable results until Masson, Professor at the École Centrale, suggested to Van Malderen, the engineer of the Compagnie *l'Alliance*, to transform the continuous-current machine into an alternating-current machine. We shall refer to this again when speaking of these machines.

Siemens' Coil.—In 1854, Siemens and Halske, of Berlin, advanced the question a good deal by inventing the coil which bears their name, and which we shall find again in a great number of apparatus, such as Wilde's, Ladd's, Marcel Deprez's, etc.

Siemens' coil is a soft-iron cylinder with two longitudinal grooves parallel to its axis, which give it, in

transversal section, the form of a double T. An insulated copper spiral fits into the grooves, and the extremities of the spiral are fixed to the two halves of a commutator for the reversion of currents, as in Clarke's machines. By turning the coil rapidly between the poles of a magnet, induction currents are produced in the wire, owing to the alternately inverse polarities of the two enlarged poles of the coil; these currents are subsequently reversed and collected in the usual manner. In 1879, Marcel Deprez modified Siemens' machine by placing the axis of the coil parallel to the arms of the magnet. For equal weight, Marcel Deprez's machine is more powerful than Siemens', because it utilizes more effectually the magnetism of the magnet.

We shall refer to it again in connection with electric motors; for Siemens' machine, and electro-dynamic machines with continuous currents generally, are reversible, that is, if they develop electricity by expending work, they can also produce work by expending electricity.

Finally, Gramme's machine, laboratory size, ought to find a place here, but this question must be deferred till the description of Gramme's ring and collector is given, which will be in the next chapter.

Between Siemens' coil of 1854 and Gramme's ring, which dates from 1870, a whole series of new principles must be considered, before we can speak of an invention which has given such a powerful impetus to the mechanical production of electricity.

b.—Dynamo-Electric Machines with Continuous Currents.

We know that the electric current is produced in electro-dynamic machines by a rapid motion of the induced wire of

the coils in a powerful magnetic field formed by the inductor. The power of the resulting currents depends to a great extent on the power of the magnetic field.

Wilde's Machine.—As an electro-magnet has at least twenty-five times as much power as a steel magnet for equal weight, Wilde thought that, by using electro-magnets instead of common magnets as inductors, the intensity of the magnetic field, and consequently the intensity of the resulting current, would be considerably increased.

Wilde's machine, which figured at the French Exhibition of 1867, was really composed of two machines placed one above the other. The first was a Siemens' magneto-electric machine, which transmitted the current into two large electro-magnets; these latter served as inductors to a second Siemens' coil, which formed the external circuit. Wilde's small machine feeds and excites the inductors of the second coil; it is, therefore, called an exciting machine. We shall find it again in a great number of other electric generators, both with continuous and with alternating currents. It is also sometimes called the inducing or priming machine.

One of the drawbacks of this machine is the great speed which must be imparted to the coils—2000 to 2500 revolutions per minute. This produces a very high temperature, which has to be counteracted by circulating cold water between the polar pieces of the electro-magnet serving as inductor to the coil of the external circuit.

Wilde's machine produced extraordinary effects considering its small dimensions, but even these effects have been surpassed by the machine we are about to describe.

Ladd's Machine.—Ladd's machine is the first application of a new principle, discovered simultaneously by Wheat-

[illegible] which was brought before the [illegible] on the 15th of February, 1867. [illegible] a great increase of intensity [illegible] under the influence of the [illegible] which it develops. A mere trace of [illegible] arising either from the momentary action of a [illegible] or a [illegible] magnet, or from remanent [illegible] sufficient to produce magnetizing action and [illegible] intensity of magnetism up to a certain maximum, which is beyond the power of a motion of the coil, the [illegible] of the latter and the point of magnetic [illegible] in this machine.

In Ladd's machine which is constructed on this [illegible] the field upon the two Siemens coils employed by Wheatstone with the permanent magnet suppressed.

The [illegible] magnet consists of two large iron plates [illegible] with their ends forming two straight electro-magnets [illegible] whose poles are of different sense; the two [illegible] poles are placed transversely to the two extremities of these electro-magnets. The smaller of the two transmits its current into the electro-magnets to preserve their magnetism, the second is utilized for feeding the external current. A trace of remanent magnetism in the plate of the electro-magnets is sufficient to produce, in consequence of successive overcharges, a very intense current, which imparts great power to the electro-magnets, and thus develops a magnetic field of very great intensity. This power of the magnetic field can, moreover, be regulated by modifying the speed of rotation.

The electricity produced by this machine, considering its small dimensions, considerably astonished the visitors to the Paris Exhibition of 1867.

These results have recently been surpassed by Gramme's and Siemens' machines. The great speed of the coils produced considerable heat in the machine, owing to the rapid changes of magnetism in the soft iron. The use of two machines, on the other hand, complicated the transmission of motion, entailing the employment of two wheels and two straps.

Ruhmkorff simplified Ladd's machine by arranging the two coils on the same axis and at right angles. The electro-magnet inductor has the form of a horse-shoe, and there is then only one axis to be set in motion. In the machine constructed by Gaiffe there is even only one single coil, round which two completely distinct wires are wound. One of them serves for feeding the inductors, and the other is connected with the external circuit. Gaiffe's and Ruhmkorff's instruments are of small dimensions, and only fit for laboratory experiments. As regards Wilde's and Ladd's original machines, which are powerful enough to produce electric light, they have been replaced by Gramme's, Siemens', and Lontin's machines.

Mode of Charging the Inductors of Dynamo-Electric Machines.—Whatever may be the shape of the part which receives the current, whether Clarke's or Siemens' coil, Gramme's ring, etc., dynamo-electric machines can be divided into three classes, distinguished by the manner in which the electro-magnet inductors are charged.

First Class.—In Ladd's machine, which is the type of this class, the inductors are charged by a distinct and perfectly separate circuit fed by a special machine.

Second Class.—The electro-magnets forming the magnetic field are arranged in the same circuit as the external armature and circuit. This is the arrangement invented by

Wheatstone and Siemens, in 1867, and which is now applied to nearly all dynamo-electric machines.

Third Class.—The arrangement which characterizes the machines of this class was also invented by Wheatstone, in 1867, but was only taken up again in 1880 by Siemens. This arrangement consists in placing the inductors in a shunted, and not in the same circuit, and for this purpose these inductors must be provided with a long wire of considerable resistance. The working conditions of the machines are hereby rendered much more favourable for the regularity of the current.[1] Edison's machine, of which we shall speak further on, offers an instance of this.

Principle of Gramme's Machine.—The most important progress in the mechanical production of electricity, since Siemens' and Wheatstone's discovery, is due to the invention of a former workman of the Compagnie *l'Alliance*, named Gramme. Thanks to his machine, the applications of electricity to lighting, galvano-plastic, and transmission of motive force, have made very rapid strides within the last few years.

Gramme's movable armature presents the appearance of a ring, turning round its centre and in its own plane; it can be considered as formed of a straight electro-magnet which had subsequently received a circular form, and been soldered at the end in such a manner that core was joined to core, and wire to wire.

The idea of employing a ring as a movable armature is not new; as early as 1852, Page constructed a motor founded on this principle. In 1861, Pacinotti also constructed a motor which in principle was identical with

[1] See, for further details, *La Lumière Électrique*, of the 15th of April, 1880, p. 151.

Gramme's machine; this machine figured at the Exhibition of 1881, and gained for its inventor an honourable mention.

Gramme's machine, however, in spite of the priority claimed by Pacinotti, has a real and absolutely personal value, justified, moreover, by its many successful applications which we shall describe in this volume.

To understand the action of Gramme's machine, let us recapitulate the simplest experiment of induction. Let us suppose a magnetized bar, one metre long, and a spiral conducting wire in reciprocal motion; if the spiral is brought

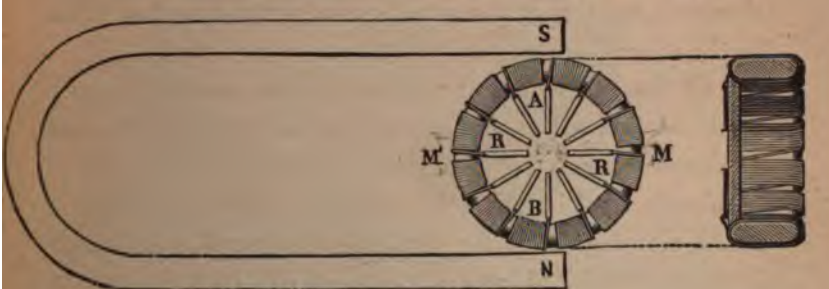


Fig. 24.—Principle of Gramme's ring.

near the bar, an induction current is developed in the former. Let us suppose that the bar penetrates into the spiral by a series of successive, uniform motions. It will be observed that an induction current corresponds to each of these motions. All these currents are of the same sense, until the spiral arrives at the neutral line; they alter their sense if the motion continues in the same direction beyond the neutral point. What is the effect produced in Gramme's ring? The iron ring is magnetized, and the magnetism is distributed in it in the following way:—

A and B (Fig. 24) are the poles, M and M′ the neutral points.

stone and Siemens, and which was brought before the Royal Society on the same day, the 14th of February, 1867. This principle consists in the gradual increase of intensity of an electro-magnetic system under the influence of the induction currents which it develops. A mere trace of magnetism arising either from the momentary action of a battery, from terrestrial magnetism, or from remanent magnetism, is sufficient to produce magnetizing action and increased intensity of magnetism up to a certain maximum, which will depend on the speed of rotation of the coil, the resistances of the circuit, and the point of magnetic saturation of its inductors.

In Ladd's machine, which is constructed on this principle, we find again the two Siemens' coils employed by Wilde, but with the permanent magnet suppressed.

The electro-magnet consists of two large iron plates surrounded with wire, thus forming two straight electro-magnets, whose visible poles are of different sense; the two Siemens' coils are placed transversely to the two extremities of these electro-magnets. The smaller of the two transmits its current into the electro-magnets to preserve their magnetism, the second is utilized for feeding the external current. A trace of remanent magnetism in the plate of the electro-magnets is sufficient to produce, in consequence of successive overcharges, a very intense current, which imparts great power to the electro-magnets, and thus develops a magnetic field of very great intensity. This power of the magnetic field can, moreover, be regulated by modifying the speed of rotation.

The electricity produced by this machine, considering its small dimensions, considerably astonished the visitors to the Paris Exhibition of 1867.

These results have recently been surpassed by Gramme's and Siemens' machines. The great speed of the coils produced considerable heat in the machine, owing to the rapid changes of magnetism in the soft iron. The use of two machines, on the other hand, complicated the transmission of motion, entailing the employment of two wheels and two straps.

Ruhmkorff simplified Ladd's machine by arranging the two coils on the same axis and at right angles. The electro-magnet inductor has the form of a horse-shoe, and there is then only one axis to be set in motion. In the machine constructed by Gaiffe there is even only one single coil, round which two completely distinct wires are wound. One of them serves for feeding the inductors, and the other is connected with the external circuit. Gaiffe's and Ruhmkorff's instruments are of small dimensions, and only fit for laboratory experiments. As regards Wilde's and Ladd's original machines, which are powerful enough to produce electric light, they have been replaced by Gramme's, Siemens', and Lontin's machines.

Mode of Charging the Inductors of Dynamo-Electric Machines.—Whatever may be the shape of the part which receives the current, whether Clarke's or Siemens' coil, Gramme's ring, etc., dynamo-electric machines can be divided into three classes, distinguished by the manner in which the electro-magnet inductors are charged.

First Class.—In Ladd's machine, which is the type of this class, the inductors are charged by a distinct and perfectly separate circuit fed by a special machine.

Second Class.—The electro-magnets forming the magnetic field are arranged in the same circuit as the external armature and circuit. This is the arrangement invented by

the expense of tension. Tension and quantity are, therefore, the two elements of an electric circulation, just as pressure and volume supplied are the elements of the circulation of fluids in hydrostatics. The energy expended in each case is the product of two factors, and this product is constant, whilst the factors vary *ad infinitum*.

Gramme's Machine with Jamin's Magnets.— Gramme has constructed a considerable number of different machines

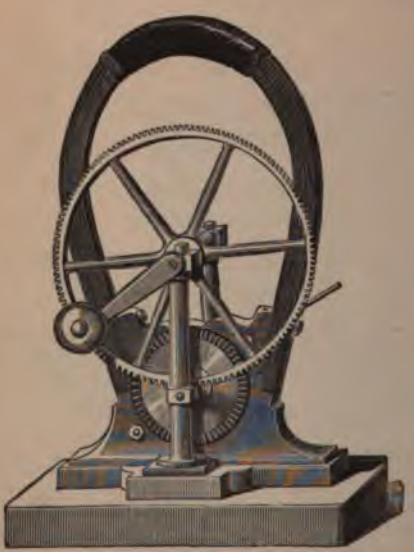


Fig. 26.—Gramme's machine with Jamin's magnet (small laboratory model).

Fig. 27.—Jamin's magnet.

founded upon the principle of the ring and collector. The one we have taken as a type to explain the production of the currents and the way of collecting them, is magneto-electric.

Fig. 26 represents the model of a magneto-electric machine to which Gramme has successfully applied Jamin's

laminated magnets. Numerous and accurate experiments have proved that laminated magnets, for equal weight, are much more powerful than ordinary magnets, provided their extremities (Figs. 26 and 27) carry pieces of soft iron which share their magnetism with the magnet.

Before the adoption of the soft-iron armatures, only five or six sheets could be superposed with any effect; with the soft-iron armature, as many as twenty can be used. Jamin's magnets have the further advantage of possessing a much larger magnetic surface—for magnetism is especially powerful on the surface—and a greater facility of mounting, dismounting, and replacing the sheets.

The magneto-electric machine with Jamin's magnets is now very much used in the laboratory. It is very easily set in motion by a pedal or a winch-handle, and it renders very good service for experiments of short duration, charging of secondary batteries, etc.

Gramme's Dynamo-Electric Machines.—However great may be the power of the magnetic field developed by a Jamin's magnet, it is far from being equivalent to that of an electro-magnet, and although, theoretically, magneto-electric machines may have a much greater efficiency than dynamo-electric ones, these latter are preferred, because, for equal weight, they transform into electricity a much larger amount of work than the former.

For these reasons, Gramme, after having constructed the machines we have described, and which are all of rather feeble power, applied to his ring the principle discovered by Wheatstone and Siemens. The first dynamo-electric machine constructed by this inventor dates from 1872; it was used for galvano-plastic in Messrs. Christofle and Co.'s works. It consisted of four electro-magnetic bars and two

coils. The first Gramme's machine intended for electric lighting had six electro-magnetic bars and three coils.

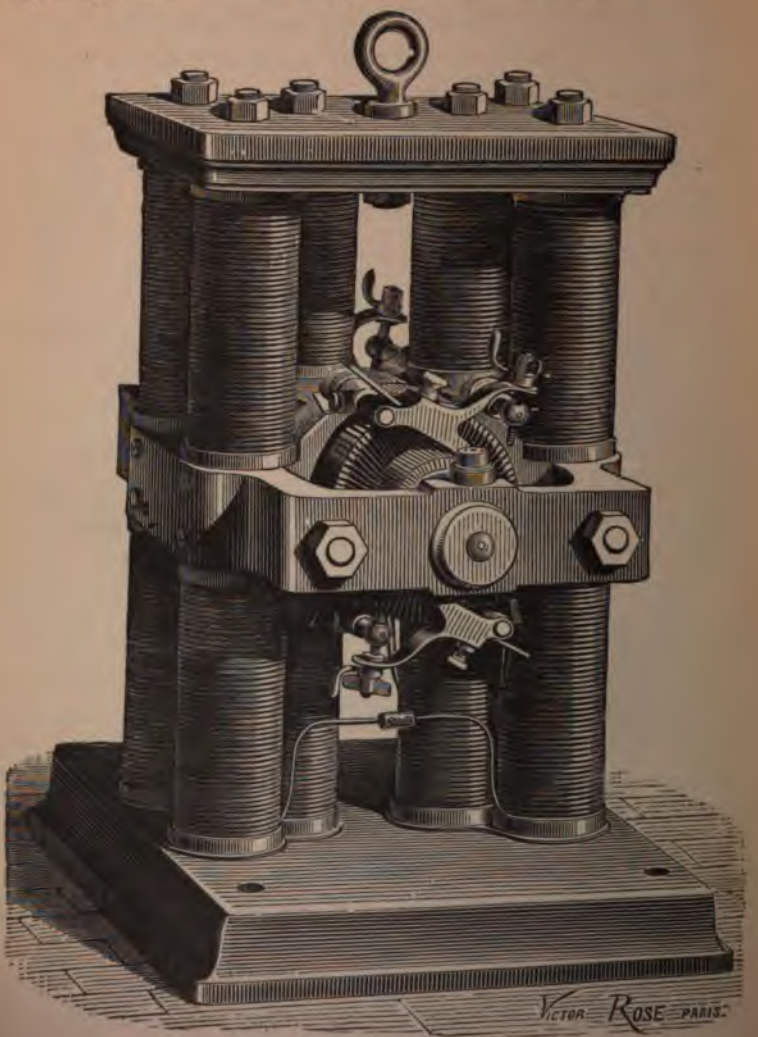


Fig. 28.—Gramme's machine, with two rings for electric lighting.

We find in these two machines the principle applied by

Ladd to his electric generator. One of the rings served to charge the inductors, the two others supplied the external current, and could be associated, according to the requirements, either for tension or for quantity.

Fig. 28 represents another, smaller, model, in which there are only two rings: one of them produces the magnetic field, and the other feeds the external circuit.

In another model, there is only one single ring formed of 120 partial coils, which are connected with two collectors placed on each side of the ring, so that all the even coils are in connection with the collector on the right, and all the odd coils with the collector on the left; the machine, therefore, works as if there were two distinct rings, which can afterwards be associated for tension or for quantity.

In this machine, the inductors are arranged in the same circuit as the coils, as indicated by Wheatstone and Siemens, in 1867; but according to Fontaine, Gramme's patent concerning this arrangement is prior to the communication of these two *savants*. By simplifying his invention more and more, Gramme has finally succeeded in constructing a machine with two electro-magnetic bars and one single central ring.

This machine is called "type d'atelier" (workshop type), or type A; it is represented in Fig. 29. We find in it again the coil and the collectors of the magneto-electric machine; the inductors consist of two soft-iron rods fixed on the frame, and carrying in their centre, where the poles are situated, two armatures, which surround three-fourths of the circumference of the ring, and thereby effectually divide the magnetic field and increase the effects of induction.

In machines for galvano-plastic, where quantity and but

little tension is required, the armature of the electro-magnet inductors is formed of a single band of thin copper, occu-

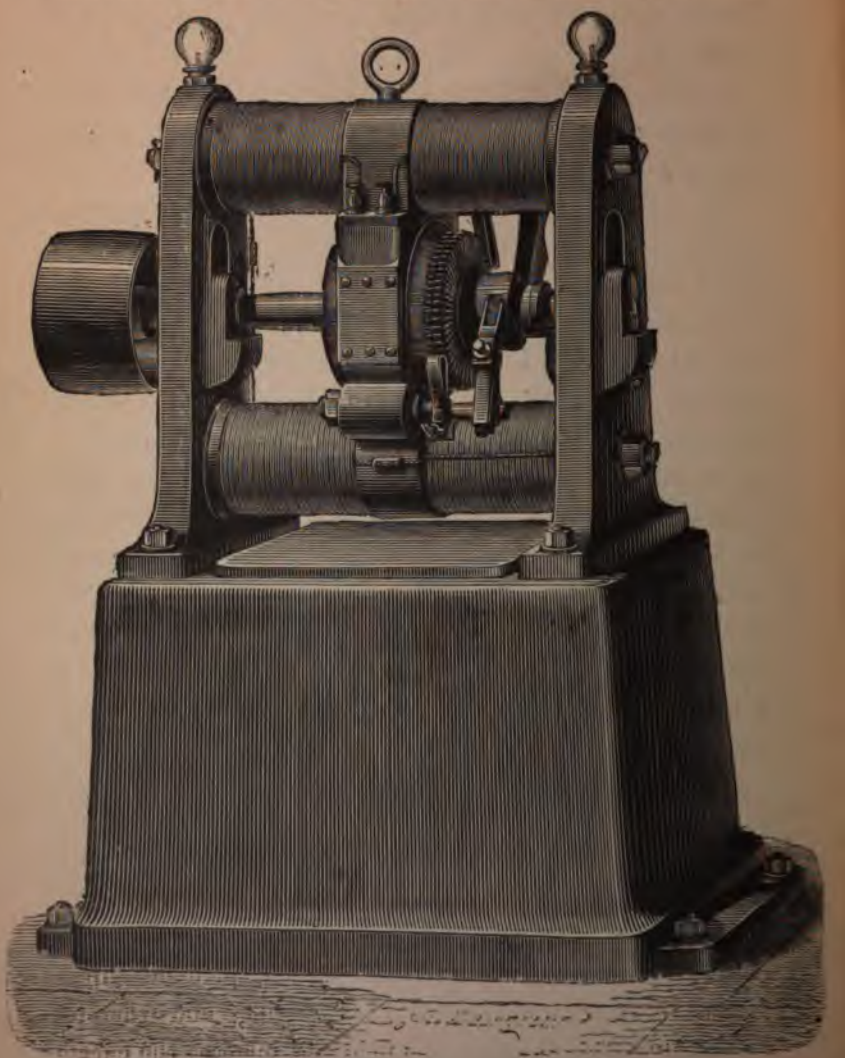


Fig. 29.—Gramme's dynamo-electric machine (workshop type).

pying the whole width of half a bar of the electro-magnet;

the coil itself is formed of very thick flat wire, strong enough to resist the effects of centrifugal force.

Gramme's machine, in its present form, realizes all the conditions of a good electric generator; its only drawback is the difficulty of coiling the ring, and this drawback is not a serious one, thanks to the improved methods of construction.

Gramme's machine transforms, under favourable conditions, eighty-five to ninety per cent. of the work expended into electricity; these figures clearly show that the efficiency of these machines leaves nothing to be desired.

The only improvements of which they are capable would be greater facility of construction and repair, and lowering of weight and price.

We are now going to describe a certain number of other machines which, although for the most part founded on the principles that have been explained, present certain interesting peculiarities on different accounts.

Schuckert's Machine.—The only interesting peculiarity of this machine consists, as Count du Moncel justly remarks in his book, *L'Éclairage Électrique*, in its being nothing but a copy of Gramme's invention.

In Schuckert's machine, the ring is flat, and the induction is effected by the lateral faces of the ring, and not in the cylindrical part. It renders the coiling of the wire on the ring even more difficult, and this can certainly not be considered an improvement; but this is the only difference we can find between the two machines.

Niaudet's Machine.—In 1872, Alfred Niaudet constructed a machine of Clarke's type with Gramme's collector. It is magneto-electric (Fig. 30), but its description, without a previous reference to Gramme's ring, would entail useless

reputation. To understand the working of this apparatus, each one must be looked upon as one of the partial coils of Gramme's ring, the bars of the commutator being connected with one another like the winding-posts of each being connected with the end-pieces of the following coil. The currents are conveyed by means of rubbers which touch the connecting points of the different coils.

The principle of the current results from the fact that

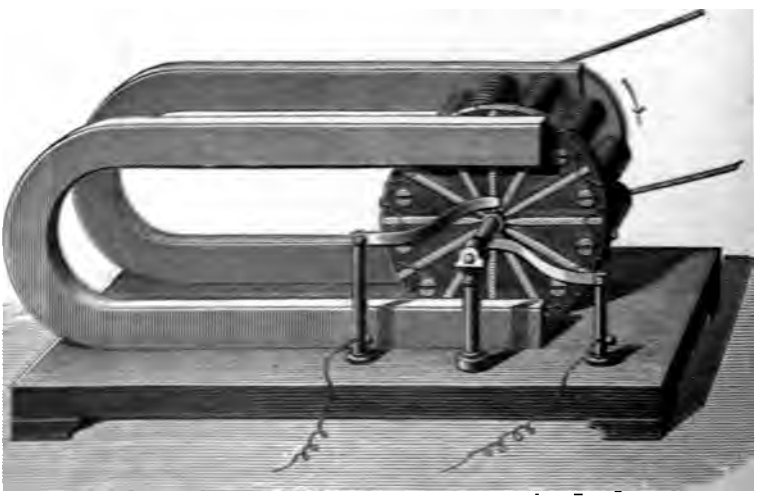


Fig. 30.—Niaudet's continuous-current machine.

the collecting springs, before leaving one of the radial pieces, already begin to touch the next.

Gramme's machines supply, for equal magnetic power and length of wire employed, a more powerful electric current, while expending less motive force; this constitutes a superiority in their favour, which Niaudet is far from contesting.

He thinks, however, that for telegraphy without

batteries, with continuous-current machines, the extreme facility of construction of cylindrical fine wire coils, with the object of obtaining currents of great tension and small quantity, will justify the employment of this apparatus, the simplicity of construction of which will compensate for its inferior efficiency—an efficiency which, in this particular case, is altogether of secondary importance.

Lontin's Machine.—Lontin's machine, patented in 1874, is

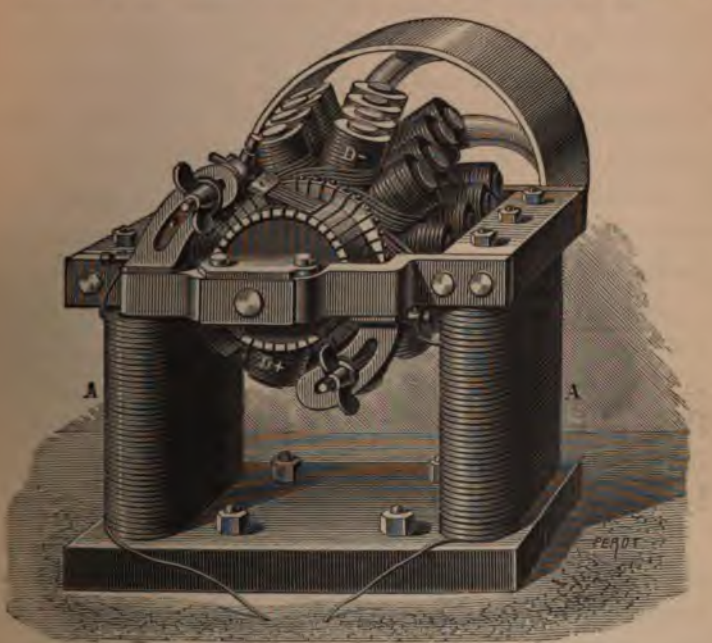


Fig. 31.—Lontin's continuous-current machine.

a dynamo-electric machine with continuous currents, with its inductors in the same circuit as the armature and the exterior circuit. It differs from Gramme's machine by the form of the armature, which is composed of forty small coils D D (Fig. 31), with their axes converging into one point,

like the radii of a circle. To this arrangement the armature owes its name of magnetic pinion.

The forty coils, divided into ten rows of four coils each, are placed after the manner of screws on each of these rows, and are provided with an iron core. They thus constitute a series of electro-magnets which, by turning between the poles of the inductor A, assume polarities of different sense at each semi-revolution.

The currents thus produced are collected on a Gramme's collector by brushes formed of the thinnest possible copper-foil. Both principle and theory of this machine are identical with those of Gramme's: the only point in which it differs from this latter is the special form of its armature.

Lontin uses this machine especially for the charging of the inductors of his alternating-current machine, which will be described on p. 90.

Siemens' Machine.—By this name are generally designated the machines invented by Hefner Alteneck, engineer in the employ of Messrs. Siemens, of Berlin. The machine (Fig. 32) is a Gramme's machine with a cylindrical armature, but it differs from the type which has served as its model by several characteristic and important details.

The induced coil, formed of sections connected with one another and with a Gramme's collector, is of considerable length and coiled in a special manner; the wire only covers the exterior part of the supporting iron frame. The induction is, therefore, only produced by the exterior face which is presented to the inductors; and the thin iron frame, which replaces Gramme's wrought-iron ring, plays a very subordinate part.

The coiling of the wire is thus rendered easier, and the coil can be fixed and centred on its axis of rotation in a much simpler manner.

The inductors, formed of a series of iron plates, are slightly arched close to the coil; this arrangement allows of a thorough division of the magnetic field, imparting to this latter its maximum density at the very point where it ought to act with the greatest energy. The general form of the machine is also very favourable to its stability. The collector and the brushes are absolutely identical with those of Gramme's machine.

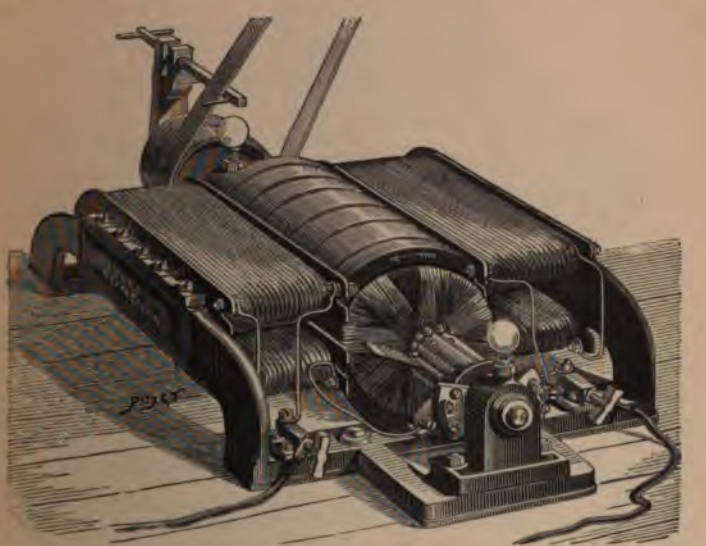


Fig. 32.—Siemens' continuous-current machine (middle size).

In this form, and by simply varying the relative dimensions of the different parts and of the inducing and induced wires, the machine can be employed for galvano-plastic, electric lighting by regulators or by incandescence, transmission of motive force, etc., like Gramme's machine.

The machine of smaller size (Fig. 33) is more especially used for charging the inductors of alternating-current machines, of which we shall speak hereafter, and differs

from the larger size by the vertical position of its inductors, by which the induced coil is kept further away from the ground. The collecting brushes are double for each pole. By this arrangement, one metallic part of the collector is always in contact with one of the brushes when the other

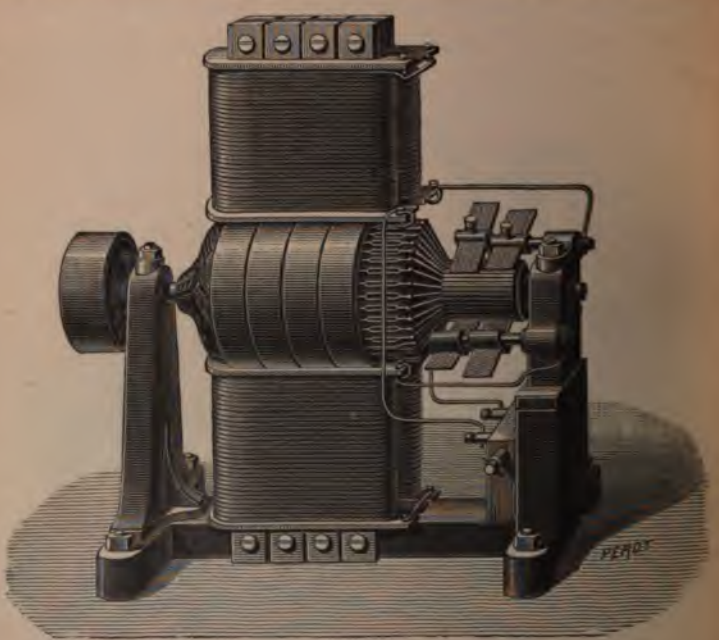


Fig. 33.—Siemens' continuous-current machine (small size).

brush meets an insulated part, and the current is thereby rendered more regular.

Wallace-Farmer's Machine.—This machine, which owes its reputation to Edison, who recommended it before he invented his own machine, is nothing but a more or less successful modification of the principle of Gramme's ring and collector. It was invented by Moses Farmer, of Boston, in 1875, and subsequently improved by William

Wallace, of Ansonia (Connecticut). It consists (Fig. 34) of a disc carrying two series of flat coils in order to utilize the surface of the discs more thoroughly; each of these coils is connected with the following, and with a Gramme's collector, as in Niaudet's machine (p. 71). The inductors are, as in Gramme's, Siemens', and Lontin's original machines, arranged for tension in the external circuit. The machine is double, and each of its halves can act indepen-

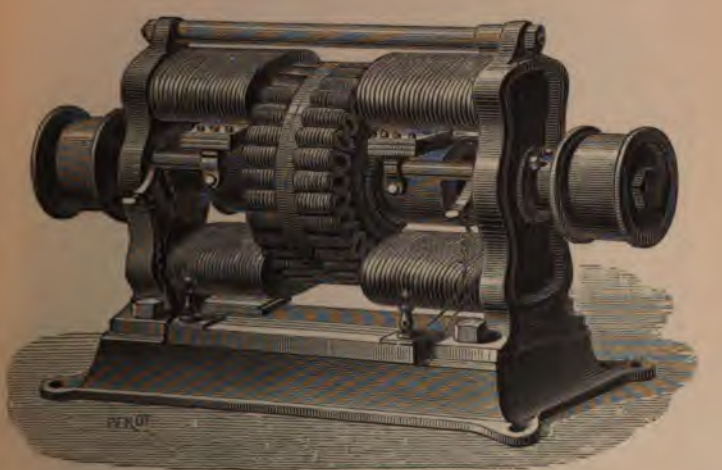


Fig. 34.—Wallace-Farmer's machine.

dently, or the two can be joined together, either for quantity or for tension.

If Wallace and Farmer are to be believed, this machine would possess the advantage of not being too much heated, on account of the large surface which it presents to the cooling action of the air; but this advantage is counterbalanced by the drawback of a considerable resistance, owing to the friction of the air. In spite of these assertions, experiments made by Houston and Thomson show that the

heat produced in the machine was sufficient to melt sealing-wax, which had been previously placed on its coils.

Brush's Machine.—The aim which Brush had in view was to construct an apparatus of high tension, and that he has accomplished this aim was shown at the Paris Electrical Exhibition, where one single machine supplied forty lamps in one circuit, or transmitted to the Opéra the necessary

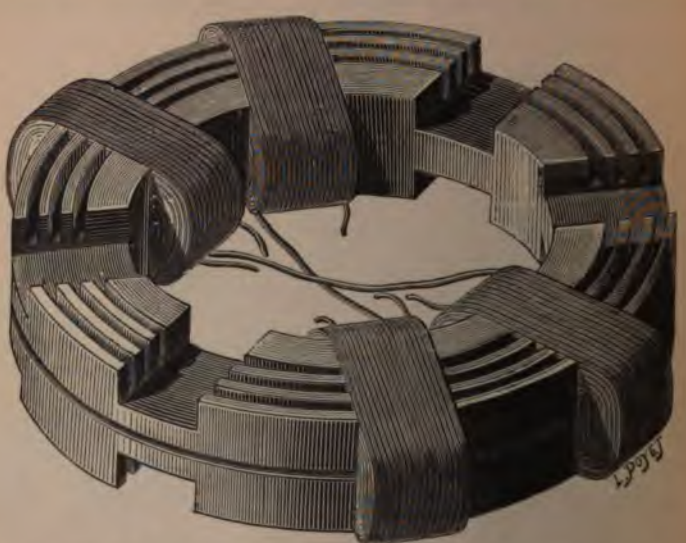


Fig. 35.—Ring of the Brush machine (four coils are taken off to show the construction of the ring).

current for supplying thirty-eight lamps in a circuit of more than six kilometres.

The machine is in principle a Pacinotti's ring, with eight or twelve coils, turning between two pairs of powerful electro-magnets, which are energized by the machine itself. Fig. 35 represents the cast-iron ring (sixteen-lamp type), and Fig. 36 the whole of the machine (thirty-two-lamp type) set in motion by a Brotherhood

motor with three cylinders. Two coils of the ring are

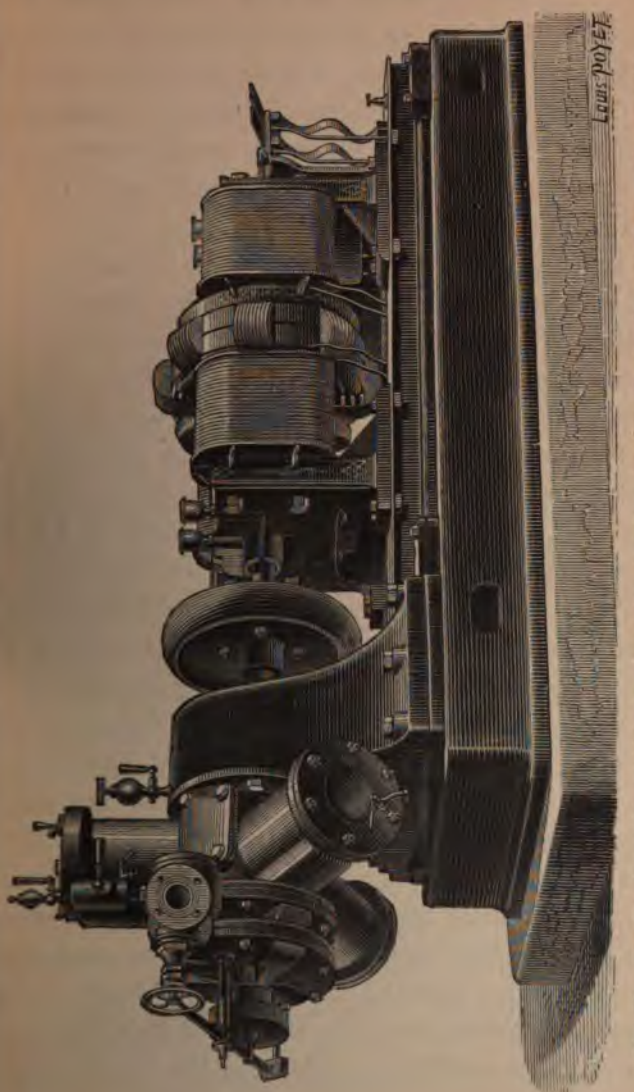


Fig. 36.—The Brush machine (thirty-two-lamp type), driven by a Brotherhood motor (from a photograph).

connected with the two diametrically opposite coils, and

so on for the whole circumference. The free extremities of the wires are connected to four commutators, very different in principle from Gramme's collectors. The ring (Fig. 35) is not one solid mass; it is cut up by deep grooves, which diminish its mass, facilitate the cooling by enlarging the surface, and prevent to a certain extent the generation of Foucault's currents, which are produced by the rapid motion of the ring in the magnetic field.

To explain the working of the machine, let us take one pair of coils and examine it separately during one complete revolution. It will be found that it is traversed by two currents of contrary sense, and that therefore, at the moment of the inversion of these currents, which will be twice for each revolution, no current and consequently no electro-motive force will be generated in that particular pair of coils. To prevent the current generated by the machine from traversing the coils at that particular moment —which, of course, would be a pure loss—Brush short-circuits, by means of a commutator, the pair of coils at the moment when they are not traversed by any current.

The collectors transmit the current to the inductors and the external circuit. To regulate the power of the machine, Brush introduces a shunt of greater or lesser resistance between the extremities of the wires of the inductors. The current is thereby divided between the inductors and this shunt; the magnetic field, and consequently the electro-motive force of the machine, is more or less weakened, without interfering with the speed of the machine.[1]

Bürgin's Machine.—In 1877, Bürgin, of Bâle, in order to bring the mass of the ring closer to the inductor, con-

[1] A detailed description of this machine and of the Brush system will be found on p. 270.

structed a dynamo-electric machine, in which the induction is effected on six distinct rings, mounted alongside one another on the same shaft. The magnetic core of each ring is a square frame of iron wire, round which are wound the spindle-shaped screws forming the armature, thicker in the middle, so that the corners of the square frame are nearly in the same circumference as the external spirals of the spindle-shaped screws, and thus pass very close by the poles of the inductors. The six rings are mounted in somewhat slanting direction, so that the coils present themselves in succession before the inductors, as in Lontin's magnetic pinion. The twenty-four coils are connected with one another, and also with a collector, like the coils of Gramme's machine, and the working of the two is identical.

The inductors are of cast iron, and mounted for tension on the general circuit. This machine has the advantage of being simple, of easy construction, and allows of a precise adjustment of the rings on the axis of rotation; it has a decided advantage over Gramme's ring in this respect.

Hefner Alteneck's Machine.—This machine is quite new, and a complete description of it would necessitate a reference to Siemens' alternating-current generator, which will be described later on. By an ingenious arrangement of commutators and collectors, Hefner Alteneck succeeded in transforming the alternating-current machine into a continuous-current machine. The experiments made with this machine are too recent to allow us to judge of its practical value; but the result is interesting, in so far as it shows the prevailing tendency of inventors to create continuous-current machines which are capable of a more general application than machines with alternating currents.

Edison's Machine.—Edison's coil is exactly like Gramme's,

with Siemens arrangement for coiling the wire, and with Gramme's collector.

The inductors are not in the general circuit, as in all other machines. The magnetic field is produced by immense horse-shoe electro-magnets which receive the current from a special machine, as in Wilde's machine, invented in 1867.[1]

Various Machines.—The number of new machines with numerous minute variations daily in almost alarming proportions, and it is almost impossible to keep pace with them. We have restricted ourselves to the description of those apparatus which present any new or interesting details of construction.

Marin, of New York, has constructed a generator with Gramme's ring and Siemens inductor, which is chiefly characteristic for its mode of current regulation. We shall refer to this machine again in the chapter on the applications of electric lighting.

Weston's special aim was the ventilation of the ring; he made it open so as to allow of a free circulation of air.

Jürgens, of Copenhagen, who wished to utilize both sides of Gramme's ring, has proposed to place a second fixed conductor inside the ring, and thus to act on both its sides. Experience alone can show whether there is any practical advantage to be gained from this rather complicated arrangement.

Gülcher uses for his lamps (with voltaic arc), which are all placed on shunts, a machine with four coarse-wire poles, with the view of producing quantity. The Gramme ring is flattened, and the two opposite inductors are

[1] An account of Edison's new machine, exhibited in the Paris Electrical Exhibition, will be found in Part II. chap. iv.

connected by a U-shaped armature, which surrounds the ring to excite it on three sides.

We must here close the list of continuous-current machines. Their number is legion, and only part of them have been tested in practice; experience alone will enable us to select the really practical ones from amongst so many.

B.—Machines with Alternating Currents.

If we consider a spiral of an induced coil during an entire revolution of the movable mass—inductor as well as armature—round its axis of rotation, we find that in all machines which we have considered till now, each spiral was traversed alternately by two or an even number of currents of opposite direction. These currents were collected, more or less successfully, in the external circuit, so as to obtain them always in the same direction, and to produce a continuous current. For certain applications it is absolutely useless to invert these currents. In certain machines, as for instance those of the Alliance, this inversion of currents could only be effected with great loss, which might easily be avoided if we content ourselves with collecting the currents without inverting them. Machines which realize these conditions are alternating-current machines, and are divided into two classes, like the continuous-current machines: into machines with permanent magnets and machines with electro-magnets.

We will briefly examine the principal types of these machines, with special reference to the new inventions of Lontin, Gramme, and Siemens, which have lately enabled us, to a certain degree, to divide the electric light by means of electric candles, and rendered possible the construction of differential lamps, of which more hereafter.

a.—Magneto-Electric Machines with Alternating Currents.

It suffices to suppress the inverting commutator of the electro-magnetic machines of Pixii, Clarke, Page, Siemens, etc., and to replace it by a simple collector, in order to obtain apparatus with alternating currents, whose power will depend, as with continuous-current machines, on the intensity of the magnetic field, the velocity of rotation of the coils, their dimensions, number, etc.

Alliance Machines.—In 1849, Nollet, Professor of Physics at the École Militaire of Brussels, constructed a Clarke machine on a large scale, and this machine is now known under the above name.

After endless disappointments, of which the details are to be found in Count du Moncel's *Exposé des Applications de l'Électricité*, the Alliance machines, originally intended to give continuous currents, were, on the advice of Masson, Professor of Physics at the École Centrale, transformed into alternating-current machines. They gave, by this simple change, incomparably better results, and were adopted, as early as 1863, for the electric lighting of the lighthouses of La Hève.

The Alliance machine is well known now; we shall simply indicate its principle. It is a Clarke machine of large dimensions, and its construction renders the multiplication of induction coils and induction magnets an easy matter.

For this purpose the coils are arranged on discs, and turn between the horse-shoe magnets, placed all round the circumference; each disc carries from eight to sixteen coils. The largest machine constructed up to the present carries

six discs of sixteen coils each, and fifty-six inducing magnets. For each turn of the machine the wires of the coils are traversed by currents, which change their direction each time a coil passes before the poles of the inductors.

For a speed of 400 revolutions per minute, more than 100 changes of the direction of the current are obtained per second. The connections of the coils with the collectors can be arranged so as to satisfy either quantity or tension.

The Alliance machines with alternating currents are good machines, working very regularly, and of considerable efficiency; they are not extensively used, because they occupy a considerable area in proportion to their power, are too heavy, and their price is too high for the work they transform into electricity. From this point of view they can be compared with low-pressure engines with condenser and low speed, of good efficiency, but to which we prefer engines of great speed, high pressure, and without condenser, because they are, with equal power, less heavy, less expensive, and less cumbersome.

De Méritens' Machine.—The machine invented in 1878 by De Méritens is also magneto-electric, but it differs from the Alliance machines by the shape of the coils, and by the way in which the induction currents are developed in the wires surrounding the induced ring.

We borrow the theory of this machine from Du Moncel's work on *l'Eclairage Electrique*—

"To understand the working of De Méritens' machines, let us suppose a Gramme's ring (Fig. 37) divided, for instance, into four sections, magnetically insulated from one another, and thus forming four arched electro-magnets, placed end

to end. Let us suppose the iron core of each of these sections terminating at its two extremities in an iron piece A B, forming, as it were, an enlargement of its poles; and let us suppose that all these pieces, united by means of a copper piece C D, constitute a solid ring, around which are placed permanent magnets, N S, N S, of alternately inverse polarity. Let us consider what will happen when

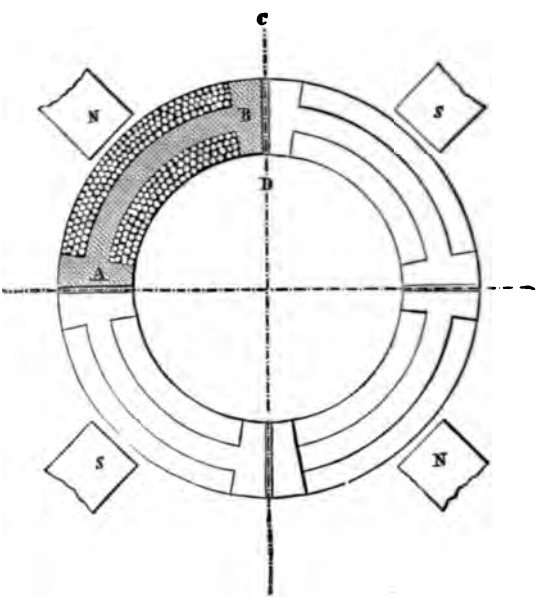


Fig. 37.—Theoretical diagram of De Méritens' machine.

this ring accomplishes a rotation round its axis. The enlarged pole B, on its way from left to right, approaches N; at this moment an induced magnetic current will be developed in the electro-magnetic helix A B, as in a Clarke's machine. This will be an instantaneous current of inverse sense to Ampère's particular currents of the inducing magnet; it will be very strong, on account of the proximity

of B to pole N. In the core A B a series of magnetic displacements will occur, which will give rise to a series of currents of inverse polarity, from B to A; these currents will be direct with regard to the particular currents of N, but they will not be instantaneous, and will go on increasing in strength from B to A. Dynamic induction currents, resulting from the passage of the spirals of the helix before pole N, will be joined to these currents. When A leaves N, a demagnetizing current will be produced, equal in strength and of the same direction as the magnetizing current resulting from the approach of the enlargement B to pole N. The effect is in reality produced at a different extremity of the magnetic core, and the helix presents itself to the action of the inductor in an inverse sense. Hence the induced currents will be inverse to the inductor from the fact of the approach and withdrawal of the enlargements A and B, and we have direct induced currents during the passage of the length of core A B S before the inductor, and direct induced currents resulting from the passage of the spirals before N. All the causes of induction are thus united in this combination.

"The action which has been described for a single section of the ring can be effected at the same time for all the others, and to it will be added the currents resulting from the lateral reaction of the poles A and B on the neighbouring poles.

"In order to strengthen the effects of induction, M. de Méritens forms the core A B and the enlargements A and B with thin iron blades, cut out with a cutting machine, as shown in Fig. 38, and placed alongside of each other in bundles of fifty, of one millimetre thickness each.

"The wires of the helices are joined in such a manner

that the indirect currents can be associated for tension, quantity, or series, according to the special requirements. In the theoretical diagram which we have given, we have only considered four sections, but in reality there is a much greater number, and in the model of which we have spoken, there are sixteen which can be easily distinguished (Fig. 39).

"They are mounted on a bronze wheel, which is fixed to the shaft of the motor. The inducing magnets are placed above this wheel; they are securely fastened to two

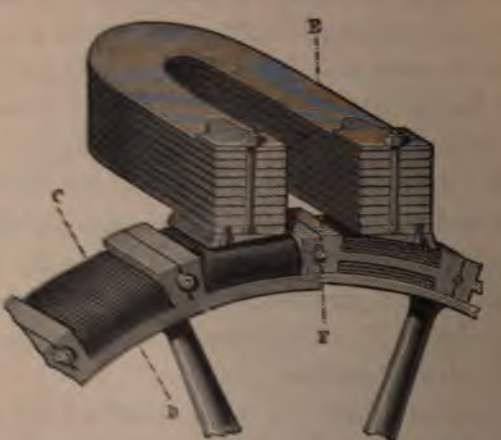


Fig. 38.—Details of De Méritens' machine.

bronze frames, and arranged horizontally. Fig. 39 will show how the different parts of this machine are mounted.

"It will easily be seen that the construction of the induced ring presents the most favourable conditions from a practical point of view. Each section being separate, it can be dismounted separately, and supplied with a coil of wire without any trouble. Whoever knows the difficulty which the coiling of Gramme's ring presents will be able to

appreciate this advantage. The arrangement of the core, with the blades placed alongside of each other, and which can be cut by one single operation of the cutting machine, is another immense advantage, rendering unnecessary the great precision in the construction of these rings, which

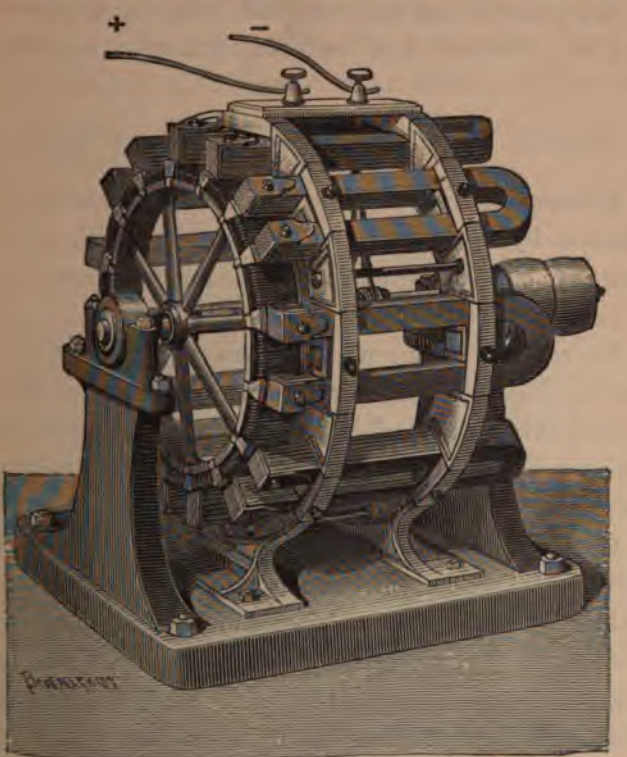


Fig. 39.—De Méritens' machine.

can only with the greatest difficulty be kept perfectly round. Finally, there is no commutator and no collector in these machines, and therefore no loss of current. From three to four Jablochkoff candles can be fed by the currents of this machine; it can likewise be used for the

lighting of regulators, and in this latter case the carbons can be at a distance of five centimetres from each other without the light being extinguished."

M. de Méritens has quite lately transformed his machine into an electro-dynamic machine, with the object of increasing the power of the inductors, and, with them, that of the machine. We shall describe this modification on p. 98.

b.—Dynamo-Electric Machines with Alternating Currents.

Dynamo-electric machines differ from magneto-electric machines by the nature of the inductors, which with the former are electro-magnets, while steel magnets are used for the latter.

In continuous-current machines the current of the machine itself is used for the magnetization of the inductors; this is not feasible with alternating currents, unless special arrangements are made which will be mentioned hereafter.

It follows that, to constitute a dynamo-electric machine with alternating currents, two machines are required: one of them is called the exciting, inducing, or magnetizing machine, is of comparatively small size, and is used for charging the electro-magnets of the second, which is called the distributing, division, or light machine; this latter furnishes alternating currents in one or several circuits.

Lontin, Gramme, and Siemens all use two machines—an exciting machine with continuous currents, and a division machine; but each of these systems presents certain distinctive peculiarities of construction.

Lontin's Alternating-Current Machine.—The first dynamo-electric machine with alternating currents and special in-

duction machine was constructed by Lontin; he used the continuous-current machine described on p. 73 for this latter purpose. The current produced by it passes into the inductors of the division machine, which has the following construction:—

The current of the induction machine passes over to the pinion of the division machine by two rubbers fixed to the terminals F F (Fig. 40). This pinion, which turns

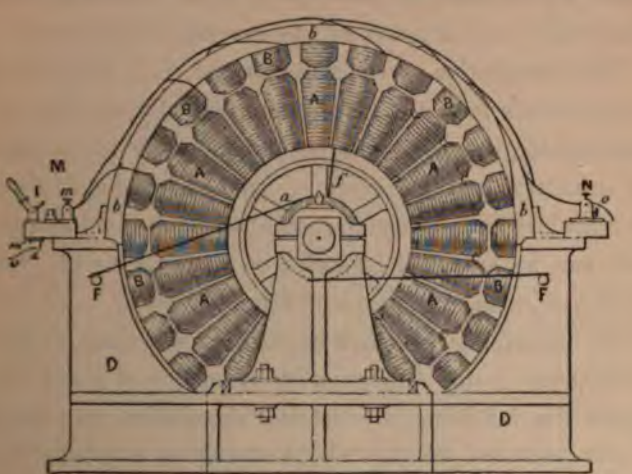


Fig. 40.—Lontin's division machine.

round an horizontal axis, is composed of twenty-four iron teeth A. Each of these teeth is surrounded by a spiral of copper wire; the current of the induction machine traverses this spiral, and magnetizes each tooth, attracting the poles on the external circumference.

A fixed crown, with twenty-four teeth fixed on the internal circumference, opposes the movable pinion, and thus forms a series of coils, which, by the extremities of the wires surrounding the core, are all connected with an

apparatus called the manipulator, whose function we are going to describe.

By communicating to the magnetic pinion a rapid rotatory motion, the teeth of the pinion, in their passage before the coils B, develop induction currents whose direction varies twenty-four times for each revolution. A machine with twenty-four coils, revolving at a normal speed of 360 revolutions per minute, produces 8640 changes of polarity in the core of the coils B; that is, 8640 currents of alternately inverse sense, or 144 inversions per second.

The extremities of the wires of the coils B are fixed to the terminals *m* of the manipulator M. By the help of the manipulator, the coils can be joined either for tension or for quantity, and in larger or smaller number. Twenty-four distinct circuits can be established, or the twenty-four coils can be arranged in series, on a single circuit, for the feeding of one single powerful focus.

In describing Lontin's regulator, we shall show the advantages of this arrangement, by means of which we can render the intensity of electrical circulation proportionate to the required effect, without changing anything in the system of the machine.

In this machine the armature is fixed and the inductor is movable, as in Pixii's multiple machine, with this difference, that the movable magnet is replaced by an electro-magnet which, for equal weight, has twenty times more power than a permanent magnet.

Gramme's Machine.—In this, as in Lontin's machine, which preceded it, the armature is fixed, and the inductors overcharged by a Gramme's machine (p. 68), are movable. The inductor (Fig. 41) consists of a magnetic pinion, formed of eight straight electro-magnets with alternating poles,

which produce in each of the sections of the induced helix alternately inverse currents. The fixed armature is a long iron cylinder, arranged like the ring of the continuous-current machine of the same inventor.

It will be seen from the diagram (Fig. 41) that, the wires of the armature being fixed, they can be joined in different ways. Every eighth part of the circumference of the ring is divided into four sections; the thirty-two sections or elements consist of eight groups of four elements each; all

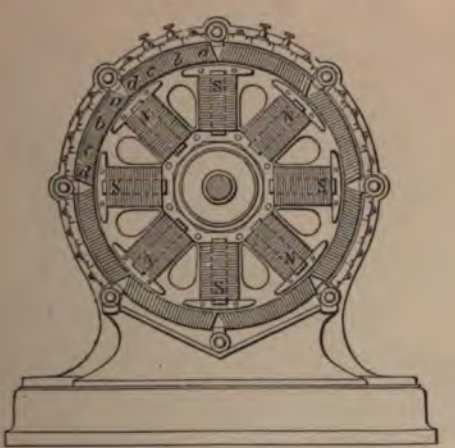


Fig. 41.—Diagram of Gramme's alternating-current machine.

the sections a are joined to one first group—for a reference to the diagram will show that all the sections a are in the same position with regard to the eight poles of the movable inductor, and therefore associated; in the same way, the sections b are united in a second group, sections c in a third, and sections d in a fourth.

By placing sixty-four sections on the ring instead of thirty-two, many other combinations are possible.

As in Lontin's division machine, there is no commutator;

two movable rubbers, in the shape of brooms or brushes, press against two distinct circles, and conduct the current from the exciting machine to the movable pinion.

The machine is enclosed between two lateral cast-iron mountings, and encased by a number of mahogany planks, which effectively protect the exterior ring against all shocks.

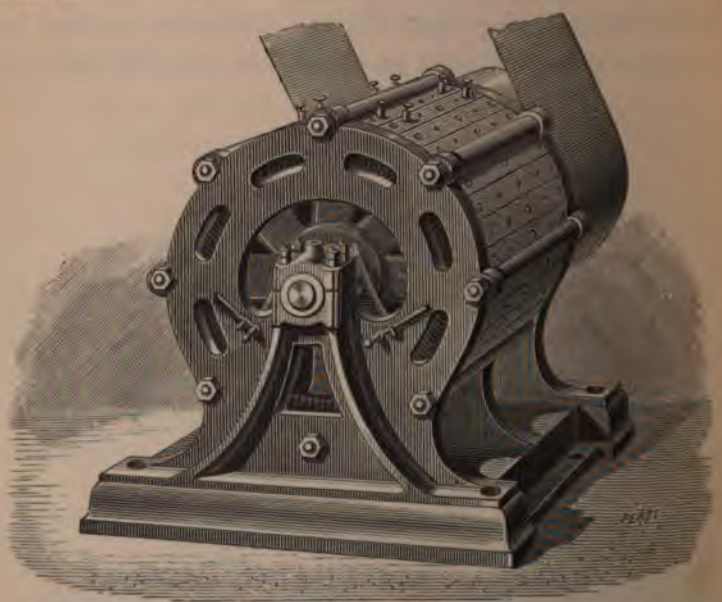


Fig. 42.—Gramme's alternating-current machine.

The diagram shows the fly-wheel and strap for setting the machine in motion. Gramme constructs machines of this type of different sizes; from machines to feed four Jablochkoff candles in one circuit, to machines as used in the Hippodrome in Paris, which produce a current powerful enough to feed sixty candles, arranged in twelve circuits of five candles each.

Siemens' Machine.—Hefner von Alteneck's machine,

constructed by Messrs. Siemens, whose name it bears, differs from Lontin's and Gramme's machines by having fixed inductors and movable armatures. The exciting machine is Siemens' small-sized machine, represented in Fig. 33, p. 76. Its current passes to an inductor formed of thirty-two electro-magnets, which are fixed to two cast-iron rings, sixteen on each side of the movable armature.

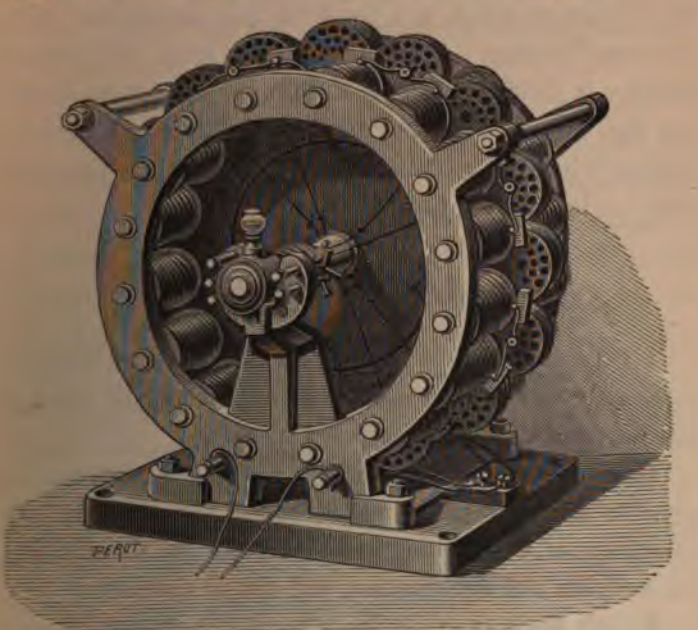


Fig. 43.—Siemens' division machine.

The extremity of the core of each electro-magnet carries a little iron plate, which constitutes an enlargement of the pole, and thus facilitates induction; these poles are alternately of inverse sense. The armature consists of sixteen flat bobbins fixed to a plate, and revolving very rapidly in the circular space between the two series of inductors. The armature bobbins have no iron core like the others;

the current is therefore developed in them merely by the passage of the spiral coils through the magnetic field of the inductors, and not by any magnetic overcharge or by the inversion of polarity of their cores.

The bobbins are previously grouped in the most convenient way for obtaining the desired results, and the currents are collected by means of brushes rubbing against the collectors, which are fixed to the extremities of the armature bobbins. A machine of this kind, with sixteen bobbins, is divided into two circuits; each of these circuits can feed ten of Siemens' differential lamps. Three conducting wires are sufficient for this purpose, for the return wire can be common to both circuits.

c.—*Self-Exciting Machines.*

All dynamo-electric machines which we have described require the use of two machines—an exciting or charging machine, and a machine properly speaking.

Machines which are worked without a distinct and separate charging machine are called self-exciting. The advantage of this arrangement consists in simplicity of transmission and construction, and also in cheapness.

Wilde's Machine.—The first alternating-current machine of this description was constructed by Wilde, as early as 1867; its use was discontinued for several years, but it is used now for the electric candles of the same inventor.

Wilde's self-exciting machine presents the same appearance as Siemens' alternating-current machine, without the enlargement of the polar extremities of the inductors and without the iron cores of the coils which form the armature in Wilde's model. To charge the inductors, Wilde employs

the current produced by a part of the coils of the armature, after having passed it into a commutator of convenient construction.

The other coils are connected with a collector, similar to that of Siemens' machine. Wilde's machine is, therefore, self-exciting in so far as the inductors are fed without the use of a separate machine. It is, in fact, a dynamo-electric machine with direct and alternating currents at the same time.

Gramme's Machine.—In 1879, Gramme constructed a slightly different self-charging machine. It really consists of two distinct machines, mounted on the same frame, and set in motion by the same shaft, and consequently possessing the same speed. One of these is a Gramme dynamo-electric machine with direct currents, for the generation of electricity; the other an alternating-current machine, analogous to the one described on p. 92.

These machines cost fifty per cent. less than those with a separate charging machine. They have the same power, are less heavy, less cumbersome, and more easily set up. Although they are not an invention of great scientific value, they represent, nevertheless, a progress of a certain importance from a practical point of view.

Schuckert's Machine.—Schuckert, of Nuremberg, whose imitation of Gramme's continuous-current machine we have already mentioned, has also invented a Gramme machine with alternating currents, in which the charging machine is altogether suppressed. For this purpose he reverses the alternating current on a certain part of the circuit, placing in this part the inductors, which are magnetized in the ordinary way by the current which has become direct.

From the want of accurate experiments, it is impossible

to pronounce an opinion on the value of Schuckert's machine, which is only known from a recent German patent. (See for further details, *La Lumière Électrique* of March 15, 1880.)

De Méritens' Machine.—M. de Méritens has modified the magneto-electric machine which we have described on p. 85, and has transformed it into a dynamo-electric machine. For this purpose he surrounds the magnets with wire coils, and transforms them into electro-magnets, but, in order to avoid the use of a separate generating machine, he excites his electro-magnets by alternating currents without reversing them.

De Méritens obtains this result by surrounding each magnet with two coils, and, by a convenient distribution of the alternating currents, he transforms each magnet into a weak electro-magnet.

By means of two distributors, each carrying as many teeth as there are poles on the circumference of the inductors, the currents pass successively into each of the inductors, but in such a way that the current passing into a given coil at a given moment is invariably of a sense favourable to magnetic overcharge.

This is an ingenious contrivance, but it is doubtful whether a great enlargement of the magnetic field can be obtained under these conditions, for the point of magnetic saturation of steel is inferior to that of soft iron. On the other hand, the introduction of the coils of the magnets into the circuit produces an increase of resistance, which weakens the intensity of the current, and counterbalances the increase of power resulting from the magnetic overcharge of the inductors.

Bürgin's Machine.—Bürgin, of Bâle, has also invented

an alternating-current machine; it consists of four rings, revolving in the magnetic field which is formed by the electro-magnet inductors. In Bürgin's machine, each of the rings feeds the inductors during the fourth part of one revolution at the very time when the sense of the traversing current is favourable for magnetization, whilst the three other rings feed the external circuit. Thus Bürgin's self-charging machine acts the part of two separate machines —one for the inductors, the other for the external circuit.

Bréguet's Hand-worked Magnetic Exploder.—This is nothing but a magneto-electric machine of the simplest construction, and is based upon Faraday's fundamental experiment. By striking the handle of this apparatus, a sudden removal of the armature ensues, and a current is generated. A second current of inverse sense is produced by bringing the armature back into contact.

This instrument, which is chiefly used for the explosion of gunpowder, requires a current of great tension. The first-named current, the one produced by the sudden removal of the armature, is used in preference to the second, for the simple reason that the movement can be more rapidly executed than the contrary one. The following ingenious contrivance increases the tension of the current:—

The lever of the armature carries a little spring, as shown on the left front of the engraving, the extremities of which are in contact with a screw. When the armature is removed from the magnet, the spring no longer touches the screw. At the moment of departure, however, the spring is tightened, and therefore the contact between the screw and the spring only ceases after the armature has accomplished two-thirds of its movement. One of the ends of the conducting wire, which is wound round the arms of

the magnet, is in communication with the lever of the armature, the other end communicates with the screw; consequently the current produced by the stroke remains shut up in the apparatus, at least during two-thirds of the time of its production. This arrangement, which at first sight seems to entail the loss of the greater part of the current, has the effect of increasing the tension, because the current produced by the apparatus is no longer a magneto-electric induction current, but an extra current of this

Fig. 44.—Bréguet's electro-magnetic exploder.

induction current, that is to say, an induction current produced at the moment of the severance of the local circuit from the magneto-electric current.

In fact, the simple addition of the spring and screw increases the tension of the current in the proportion of one to five. This is roughly shown by comparing the shocks received on placing two fingers on the terminals of the apparatus, and in a more accurate manner by the number of fuses which can be lit in either case.

This improvement, added to a careful construction of the machine, enables us to explode extra-fine sporting powder, placed between two metallic points at great distance from one another.

Exploders have been constructed which, by a single stroke, can light twenty Abel fuses; but this great power is only obtained by sacrificing the lightness of the apparatus (these powerful instruments weigh from twelve to fifteen kilogrammes). In most cases we content ourselves with smaller apparatus, weighing eight kilogrammes, which are capable of lighting from ten to twelve fuses in the laboratory, and from six to eight in the field.

Finally, in military engineering, experiments have been made with apparatus of very small dimensions and weight, capable of yielding only three or four simultaneous explosions, that is to say, a force sufficient to be absolutely certain of one explosion on the battle-field.

The exploder is the simplest magneto-electric apparatus that has ever been constructed, and we may add that it is impossible to conceive a simpler one, for it merely contains the three parts which are indispensable for repeating Faraday's experiment; they are—a magnet, an armature of soft iron wire, and copper wire surrounded with silk.

The permanent magnet of the new models of exploders consists of a laminated magnet, which, for equal weight, has a much greater power than the original magnet with three arms.

This apparatus, however, cannot be compared with Ruhmkorff's coil as regards its energy. The only advantage it possesses over that powerful instrument is that it is self-acting and always ready for action, whilst the induction coil necessitates the use of a charging battery.

Magneto-Electric Telephone Machine.—To complete the list of apparatus which transform mechanical work into electricity, we must mention the most sensitive and the most delicate of all, Graham Bell's magnetic telephone and its numerous imitations. All magnetic telephones are real electric generators, which, under the influence of the mechanical work resulting from the vibrations which constitute sound, engender undulating electric currents of an intensity proportionate to these vibrations. Thus the most powerful and the most feeble currents which we can produce have all the same origin: mechanical work.

CHAPTER IV.

APPARATUS FOR TRANSFORMING ELECTRICITY.

ALL the apparatus described in the preceding pages are veritable generators of electricity, for they engender electricity, either by means of chemical action as in liquid batteries, or heat as in thermo-electric batteries, or finally, work, as in electro-dynamic machines.

We designate by the term electric transformers apparatus in which electricity is no longer produced directly, but is transformed and changes its properties. No better parallel could be drawn than by comparing them with kinematic apparatus in mechanics. We have seen that a given source furnishes a certain volume or quantity of electricity at a certain pressure or tension. It may be of importance, in certain applications, to increase one of these properties at the expense of another, as it may be desirable in mechanics to transform speed into force or force into speed by means of fly-wheels or driving wheels.

Apparatus which allow of this transformation are called electric transformers.

It is clear that these apparatus can be divided into two large classes—such as transform the electricity they receive with a view to quantity, and such as transform it with a view to tension.

To the first class belong Gaston Planté's secondary batteries, d'Arsonval's voltaic condenser, and the batteries of Houston, Thomson, and Varley.

In the second class naturally figure induction coils, Planté's rheostatic machine, and the secondary batteries which, under certain conditions which will be mentioned hereafter, enable us to increase in very large proportion the tension of the original source.

All these apparatus, however, have a common character: they receive electricity and give out electricity, which they transform according to their individual properties.

Before describing them, a property exclusively belonging to the apparatus of the first class must be mentioned.

All secondary couples are electric accumulators as well as transformers. They can be likened to apparatus which serve in mechanics for accumulation of work resulting from the action of forces, such as hydraulic accumulators, reservoirs of compressed air, springs which are appropriately named secondary motors, etc.

Secondary couples, when charged, represent a store of available electric work, which can be expended at will, and within a shorter or longer period; they enable us to obtain in a very short time effects of tension and of quantity much greater than those of the original electric source, or inversely, to produce less intense effects, but lasting for a much longer period. We refer our readers for further details to Gaston Planté's remarkable work, *Recherches sur l'Electricité.*

Planté's Secondary Batteries.—Planté has been led to the construction of his batteries by the study of the secondary currents which are produced within a battery. Batteries with two liquids and a constant current had been

invented by Becquerel, in order to neutralize polarization. Planté, starting from another point of view, endeavoured to collect the secondary currents, and to put them to profit for the accumulation of the force of the voltaic battery. We give in his own words an account of the investigations which have led him to adopt the form of a secondary battery as it is used nowadays—

"We had found that the secondary electro-motive force of a voltameter, made of leaden sheets placed in dilute sulphuric acid, was more powerful and more lasting than that of all other metals, and that it even surpassed by one-half that of the most powerful voltaic element known, that of Grove or Bunsen. With such an electro-motive force, the only question, in order to form a secondary element of great intensity, was to give it a very feeble resistance—to enlarge as much as possible its surface. This was the more easily accomplished, as the two sheets requisite for its construction were necessarily of the same nature and of an extremely flexible and malleable metal like lead. Thus we were led to construct, in 1860, a secondary element of great intensity, by using an arrangement similar to the one which Offershaus and Hare had used for the voltaic battery properly speaking, that is to say, by forming into a spiral two long and large sheets of lead, separated from one another by a piece of coarse cloth, and immersing them afterwards

Fig. 45.—Planté's element (1860).

in a beaker full of water acidulated with $\frac{1}{10}$ of sulphuric acid.

"Fig. 45 shows the arrangement of a secondary couple of this kind."

The cloth proved inconvenient, for it introduced an additional resistance, and became useless after a while. Planté then used batteries with parallel sheets, separated by insulating rods, and placed in indiarubber troughs. But these indiarubber troughs contracted after a time, and thereby brought the leaden sheets nearer to one another by curving them, and thus gave rise to contacts. The opacity of this substance, besides, prevented the experimenter from seeing what was going on in the interior of the secondary couples, which must be watched whilst they are charged. We give here Planté's own words—

"We have, therefore, come back to an arrangement similar to the one we described first, modifying, however, the mode of separation of the leaden sheets. We separated these sheets no longer by a piece of coarse cloth, but by narrow indiarubber bands, which possess the advantage of not being affected by the acidulated water, and of only covering a very small part of the surface of the electrodes. Two pairs of indiarubber bands, about one centimetre wide and half a centimetre thick, are necessary to prevent the sheets from touching each other. The opposite extremities of the leaden sheets terminate in two small blades, so as carefully to avoid any cause of contact, and to render uniform the distribution of the primary current over the surface of the electrodes, by holding apart from one another the two points through which the positive and negative electricity pass into the secondary couple. This arrangement, however, is not indispensable, if the leaden sheets are carefully and uni-

formly rolled round each other. The chemical action of the primary current is then equally distributed over the whole surface of the secondary couple, even if the two poles of the battery are in close proximity to one another.

"The leaden sheets, separated by two or three india-

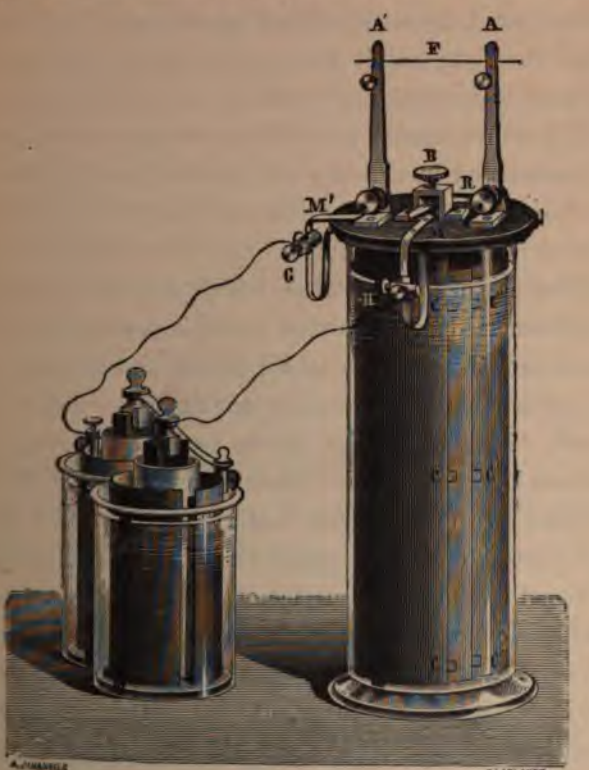


Fig. 46.—Plante's secondary battery, charged by two Bunsen elements.

rubber bands, are rolled round a wooden or metallic cylinder.

"On commencing the first spiral, it will be found convenient to place two small transversal indiarubber bands, of the same length as the cylinder, before the ends of the

longitudinal bands, in order to keep apart the edges of the two sheets of lead, which might otherwise touch. When the coiling is finished, the interior cylinder is carefully removed, and the spirals are kept in their places by means of small indiarubber cross-bars softened by heat. The couple is then placed in a cylindrical glass vessel, and fastened on the inside by small indiarubber slips. The vessel is filled with water acidulated with $\frac{1}{10}$ of sulphuric acid.

"Fig. 46 represents an ordinary couple of rather large size, constructed in the way we indicated, and at the same time shows the system of communications for the charge or discharge of the couple and for exhibiting its effects.

"The earthenware vessel which contains the leaden sheets immersed in acidulated water, is covered with a disc of hardened indiarubber, which carries the metallic pieces destined to close the secondary circuit when the couple is charged. The extremities of the two leaden sheets communicate, by means of the binding screws G and H, at the same time with a primary battery of two small Bunsen elements, and with the copper blades M M'. The blade M is fastened to the upper surface of a second copper blade R, whose prolonged extremity forms a spring, and can be lowered and pressed down by the button B, whereby the blade M is put in communication with the pincers A. Blade M', on the other hand, is in constant communication with the pincers A', and between the arms of these two pincers are placed the metallic wires destined to be heated red hot, and to be melted by the secondary current. The wires of any other apparatus into which this current is to pass can be fastened to the two pincers.

"This system of communications, fixed in the simplest possible manner to the cover of a beaker, does not break

the primary current when the secondary circuit is closed. In order, therefore, to try the effect of the secondary couple alone, this latter is separated from the primary battery by detaching the wires G and H; the button B is then pressed down. But even if these wires are left in communication with the secondary couple when discharging it, no inconvenience ensues; the action of the apparatus is not interrupted; its effects are even slightly increased by the action of the primary battery, which is added to that of the secondary couple; these two are in opposition when charged, and are associated for quantity at the time of discharge."

Chemical Action produced in the Secondary Leaden Couples.—We shall be better able to understand why secondary batteries can furnish discharges of long duration, remain charged for a long time after the action of the primary battery, and thus store the chemical work of the battery, or the mechanical work expended on the motor when the secondary battery is charged by a magneto-electric machine, by studying, with M. Planté, the action produced in the secondary couples.

"When a secondary couple of large surface is new, and the current from two Bunsen couples is passed through it, oxygen gas appears almost immediately on the positive blade; part of this oxygen oxidizes the surface of the blade, which is very soon covered with a very fine layer of peroxide of lead.

"On the other hand, the hydrogen, after having reduced the slight coating of oxide with which the lead may be covered from having been exposed to the air, soon makes its appearance; and if after a few moments the secondary current is tested, it will be found very strong already from

the vividness of the spark which is produced on closing and immediately breaking the secondary circuit with a copper conductor of small resistance. But the current thus produced is of very short duration.

"If the apparatus is charged a second time, after having closed the circuit so as to suppress the secondary current, the sheets are in a somewhat different state from what they were at the beginning. While the secondary current was closed, the oxygen, acting upon the sheet which was negative when the current was passing through it, has covered this sheet with a slight coating of peroxide; at the same time, the peroxide, formed on the other sheet during the passage of the principal current, was reduced by the hydrogen. We have therefore after a first experiment two sheets, whose surfaces have changed their molecular condition since the beginning of the experiment. They are covered with thin layers of oxide and of reduced metal, which will facilitate the ulterior action of the principal current on the secondary couple.

"If we first consider the sheet of lead which was negative while the principal current was passing for the first time, this sheet is, as we have seen, covered with a layer of oxide after the passage of the secondary current. Consequently, if the principal current passes through it again, the hydrogen given off at first will reduce this coating of oxide instead of the slighter coating merely resulting from the exposure to air, as was the case before. Therefore a longer time will elapse before the appearance of hydrogen on the surface of this sheet; for this gas will only be given off when the oxide is completely reduced to the state of finely divided lead.

"During the second passage of the principal current

through the positive sheet, the first particles of oxygen which rise to the surface meet with a layer of reduced peroxide, or finely divided metallic lead, on which the gas acts much more energetically than on the original leaden sheet; the gas is more easily absorbed, and a delay in the appearance of oxygen on this sheet will be noticed—a delay which corresponds to the time necessary for the reoxidation of the layer of reduced lead.

"When the secondary current is closed again, these phenomena are reproduced, and it is clear that, after these operations have been repeated a great many times, the surfaces of lead of the secondary couple will be in a more favourable condition for oxidation or reduction; the layers of oxide alternately formed or reduced will become thicker, and the secondary effects which result from this will be more lasting and more intense.

"And this is really what takes place: the longer a secondary couple is exposed to the action of a primary current, and the longer it acts itself afterwards, the more lasting is the secondary current."

The construction of a secondary couple requires a number of precautions, which are minutely described in Planté's work. With a well-constructed couple, twenty or thirty minutes may elapse during its charge with two Bunsen elements, provided the surface of the couple amounts to one square metre.

The whole work of the batteries is expended upon the oxidation of the lead on the one hand, and on the other on the reduction of the oxidized lead produced by the previous closing of the secondary current.

When once the gases are given off in a well-constructed couple, it may be taken for granted that the battery no

longer performs any work available for the production of the secondary current.

Power and Duration of the Discharge of the Secondary Couples.—The discharge of a well-charged secondary couple depends on the size of the sheets, the thickness of the deposits produced, and, finally, the exterior resistance of the circuit. The discharge is very constant as long as the battery contains electricity stored in the form of chemical work.

In the same way as in a very large and shallow vessel the liquid will flow for a long time and steadily from a small opening, and cease suddenly as soon as it stands below the opening, so a secondary couple of large surface, which heats a metallic wire to redness or produces a deflection of the galvanometer, will only show a diminution of intensity a few moments before the action ceases altogether.

The fact is striking, when the secondary current is discharged by making it traverse a platinum wire. The incandescence remains uniform for a long time, and ceases suddenly as soon as the store of chemical work accumulated in the couple is exhausted.

The electro-motive force of a well-constructed secondary couple reaches about two volts and a half; this explains why at least three Daniell or two Bunsen elements are required for its complete charge.

The feeble interior resistance of the couples, which varies between $\frac{1}{20}$ and $\frac{1}{30}$ of an ohm, explains the quantity furnished by these instruments. Planté's elements can also be charged with Gramme's laboratory machines, and Fig. 47 represents this experiment; but in this case the speed must not fall below a certain point, or the battery would discharge itself into the machine to no purpose. To prevent this incon-

venience, an automatic joining and disjoining arrangement has been constructed, which removes the secondary battery from the circuit as soon as the electro-motive force of the machine becomes too feeble to charge it, and places it back into this circuit as soon as the electric-motive force has become sufficiently strong to effect the charge. (See *La Lumière Électrique*, June 15, 1880.)

The secondary couples can preserve the accumulated charge for a long time. Thus a well-constructed and well-

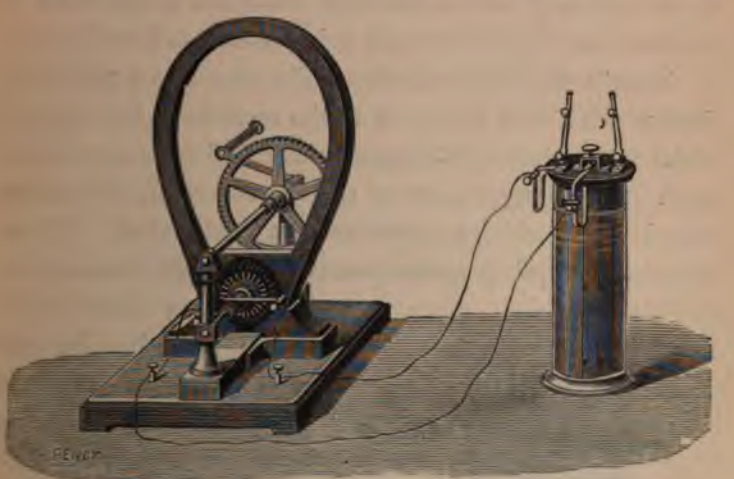


Fig. 47.—Planté's element charged by a Gramme's laboratory machine.

charged secondary couple can heat to redness for a few minutes a platinum wire half a millimetre thick, even two or three weeks after having been charged.

Planté has even obtained this effect with exceptionally well-constructed couples more than a month after their charge.

The same observer has measured the proportion of the electric work restored by the discharge, to the electric work

expended for the charge, by decomposing copper sulphate in a voltameter. The efficiency has been found to be from eighty-eight to eighty-nine per cent.; the secondary couple is, therefore, a rather perfect accumulator of the work of the voltaic battery.

It is to be regretted that Planté has not continued his experiments by calculating the number of calories stored up or the number of kilogrammetres which a well-charged couple can furnish. These figures would be very useful for certain applications, for they would show the value of the secondary couple from the point of view of its efficiency.

Planté's Electric Tinder-box.—Fig. 48 shows a particular form which Planté has given to the secondary element, and which he has called "le briquet de Saturne" (Saturn's tinder-box). On the upper part of the box two small pincers are seen, between which a platinum wire is stretched. Whenever the two springs at the bottom are brought into contact by touching them with the finger, the battery current passes through the platinum wire, heats it to redness, and immediately lights a candle. A candle can be lit a hundred times with this apparatus before the latter requires to be charged anew with three Daniell elements. This is a new and very inexpensive way of obtaining a light, for the secondary couple itself expends nothing, and the charging battery only consumes a few grammes of copper sulphate for a very long period of work

Fig. 48.—Electric tinder-box, with Planté's secondary battery.

on the part of the tinder-box. This same apparatus can be used for firing mines in civil and military engineering; experience shows that, with fuses of fine platinum wire ($\frac{1}{20}$ of a millimetre), a mine can be exploded at a distance of 900 metres, by means of a copper wire of that length and of three millimetres thickness.

Faure's Storage Battery.—This battery, which has lately attracted so much attention, is an improvement upon Planté's apparatus.

Faure has conceived the happy idea of filling up the space between the lead plates used by Planté with red lead, with the result of vastly increasing the usefulness of his apparatus. The advantages which red lead offers for this purpose are due to the fact that it is an intermediate oxide, which more oxygen can raise to the state of peroxide, while hydrogen can reduce it, first to protoxide, and then to metallic lead. The apparatus consists of a number of wooden trays, about one foot square, with half a pound of red lead spread over the bottom; on this is placed a lead plate; then a piece of flannel, to prevent the possibility of contact; then another half-pound of red lead; and lastly, another lead plate. The trays are filled with dilute sulphuric acid.

The chemical work in this apparatus is the following:—Upon each upper plate oxygen has been liberated, and has partly united with the lead itself, and partly with the red lead in contact with it, producing in each case peroxide of lead. At each of the lower plates hydrogen has been set free, and has actively reduced the red lead to the condition of spongy metal. There now will be great chemical dissimilarity between the upper and lower plates, of such a kind as to be capable of producing a powerful electric current.

The practical usefulness of Faure's batteries rests on the possibility of getting from them a high percentage of the energy passed into them, and it is a remarkable fact that there is infinitely more power returned than from steam-engines, water-wheels, etc.; for while a good steam-engine only returns ten per cent of the energy evolved by the combustion of the coal, and a first-class water-wheel sixty-eight per cent. of the energy of falling water, a Faure's battery will give back ninety per cent. of the energy expended in charging it. But it must be borne in mind that, in order to deal with large quantities of energy, lead must be used profusely—small surfaces are only of use for small charges. And again, care must be taken that the charge shall be regulated to the extent of the surface, if economical work is to be accomplished. Should the charging take place too energetically, much waste will ensue, because the oxygen and hydrogen will be given off too quickly to properly act on the red lead, and will therefore escape uselessly; while, on the other hand, if the charging is too slow, some of the reduced lead may again become oxidized. And further, when a feeble source of electricity is employed to charge a large number of accumulators, it will be more economical to charge them a few at a time. They may afterwards be connected together, and used as one powerful combination.

For all practical purposes, the source of electricity used would be some form of dynamo-electric machine. Now, for lighting by electricity directly with such a machine, the greatest care has to be taken to prevent irregularity in the motion of the steam-engine which drives it, for every small jerk or other unevenness produces flickering in the light. The Faure battery at once provides a means of getting

over this difficulty, for, if the dynamo-electric machine be employed to charge it, the battery may afterwards be connected with the lamps, and a steady current and unflickering light be produced, no matter how irregular the process of charging may have been. And this battery also provides a means by which waste energy can be economically utilized. It very often happens in factories that steam-engines are wasting steam, because less work than usual is being done by the machinery, and it is plain that if a dynamo-electric machine were arranged so that it could easily be put in gear, this waste need no longer take place, for the batteries could very well be charged at such times, and the stored energy would be available for lighting up or for driving motors.

Sutton's Electrical Storage Battery.—This storage battery, which has been quite recently invented by Henry Sutton, of Ballaarat, Victoria, has a negative electrode of copper, and a positive electrode of lead amalgamated with mercury, immersed in a solution of cupric sulphate.

The chemical changes in this cell are exceedingly interesting and beautiful, the cell being composed of a sheet of lead cleaned with sulphuric acid and amalgamated thoroughly with mercury, and a sheet of thin copper a little shorter. The two sheets are perforated with a number of holes and then rolled in a spiral, separated by rubber bands cut every five inches; the holes in the plates and the cuts in the rubber bands being to allow free circulation of the solution (the short plate being uppermost before rolling). The combination is immersed in a solution of cupric sulphate, and the amalgamated lead plate made the positive electrode of a suitable source of electricity; the chemical action being that the oxygen of the decomposed solution combines with

the lead, forming a perfectly even coating of the insoluble peroxide, the hydrogen replacing the copper of the solution, and the copper being deposited in the metallic state on the negative electrode. As the decomposition of the cupric sulphate proceeds, the solution gradually loses its azure blue colour, becoming more acid; and finally, when the whole of the copper is deposited, we have the solution colourless and transformed into hydric sulphate and water, the positive electrode peroxidized, and copper deposited on the negative electrode. During discharge, the peroxide is reduced and the copper element oxidized, the oxide combining with the acid and forming cupric sulphate, the solution returning to its original colour. This change of colour forms a beautiful means of telling when the cell is charged; it is a veritable charging gauge. The power of this cell is very great and very constant; it can be made to last for hours, the time being dependent on the quantity of cupric sulphate decomposed.

Sutton obtained, by the decomposition and recomposition of one pint of cupric sulphate, over two hours' effective work in heating to a red heat one inch of No. 28 iron wire, the cell measuring internally four inches deep and four inches diameter.

A practical form of cell for storing purposes may be made by fixing a series of amalgamated lead plates in a box in grooves, as in Cruikshank's trough battery, filling the intervals between the plates with solution of cupric sulphate, and passing a current through of sufficient tension to overcome the contrary electro-motive force of the series, the positive sides of the plates being peroxidized, and copper deposited on the negative sides. Each box contains twenty-five of these plates, and a number of these boxes

can be coupled for quantity while charging and for tension during discharge.

This battery is a powerful and constant source of stored energy; the cell does not polarize itself during discharge, as is the case in both Planté's and Faure's cells,—in these cells the peroxide formed by the discharge produces a contrary electro-motive force.

Houston and Thomson's Storage Batteries.—In the apparatus invented by these two Americans, the secondary phenomenon on which the principle of accumulation is founded is nothing but the chemical decomposition of a salt—zinc sulphate in this particular case—by the electric current.

Houston and Thomson propose to store the current produced by dynamo-electric machines, and to utilize it for telegraphic apparatus, electric bells, fire alarms, domestic motors of small power, etc., etc.

Fig. 49 represents the principle of their storage battery, and Fig. 50 a series of elements arranged for tension, to produce more intense effects.

In Fig. 49, B is a copper plate joined to the terminal *b*, and C a carbon plate connected with the terminal *c*. The vessel A, which contains the two plates, is filled with a solution of zinc sulphate; E is a porous diaphragm which separates the two plates.

If the current of a dynamo-electric machine traverses the apparatus in the sense *b c*, the zinc sulphate will be decomposed, and metallic zinc deposited on the carbon plate C, whilst in the lower part of vessel A a concentrated solution of copper sulphate will be formed. The length of time during which the deposition or the charge lasts is only limited by the quantity of zinc sulphate contained in the

[illegible] the [illegible] of the copper plate B. This arrangement constitutes therefore a gravity element similar to that of Callaud, in which a decreasing an electric current is sent in the direction from the copper plate B to the zinc plate A, covered with zinc.

In an element that works [illegible] battery formed in this manner a crystal [illegible] is deposited, and copper [illegible] upon the lower plate B. Houston and Thomson [illegible] therefore, in reality, only Callaud's battery in which the zinc is recovered from the zinc sulphate by

Fig. 49.—Simple element.

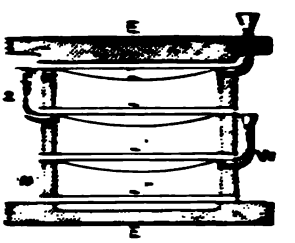


Fig. 50.—Series of elements.

Houston and Thomson's electric storage batteries.

utilizing the mechanical work of a steam engine, which drives the dynamo-electric charging machine.

Fig. 50 represents a series of couples mounted for tension. L, L', L'', L''' are copper plates, separated by insulating rings; the intervals between these plates are filled with a solution of zinc sulphate; the lateral tubes *d* allow the expansion of the liquid. The charged battery is similar to Volta's columnar battery.

The storage of electricity no longer depends on the surface of the plates, but on the quantity of zinc sulphate, which of course is a great advantage, but since the electromotive force of each element is equal to that of a Daniell

element, and since the interior resistance must be very great, a considerable number of elements will be required to produce an appreciable effect, and even if there be a gain from the fact that the battery can continue its activity for a much longer time without requiring a fresh charge, yet it appears that, for equal power, this apparatus must be much more cumbersome and much heavier than Gaston Planté's secondary battery.

D'Arsonval's Voltaic Condenser.—At the very same time that Houston and Thomson were constructing their storage battery in America (October, 1879), M. d'Arsonval, Demonstrator at the Collège de France, was studying the same question, with the view of increasing the charge stored in Planté's secondary battery. In a memorandum presented to the Académie des Sciences on the 26th of January, 1880, he describes his secondary couple, which consists of a zinc plate and a carbon plate placed in a porous vessel full of granulated lead or small shot, the whole impregnated with a concentrated solution of zinc sulphate.

If the couple is charged by a current passing from the carbon to the zinc, the zinc salt is decomposed, the oxygen forms peroxide of lead on the small shot, and the sulphuric acid remains in a free state. The deposition of the oxidizable metal zinc is therefore no longer limited, and the oxygen can accumulate in larger quantity in the form of peroxide of lead. Manganese can be substituted for lead, silver for copper, and the results will be equally satisfactory; but none of these can be compared to the peroxide of lead adopted by Planté.

Such is D'Arsonval's apparatus; a couple containing a kilogramme of small shot can keep in motion for four hours one of Marcel Deprez's small motors.

M. Varley has also invented secondary batteries constructed on a principle similar to that of Houston and Thomson.

Planté's, Faure's, and Sutton's secondary batteries, however, are without contradiction, the best of all, and the two former have already received important applications in practice. The question of storage of chemical work in secondary batteries, and its recovery in the form of electricity, presents the greatest interest and has the greatest future. We shall say a few words about it when we come to the electric motors; researches on this subject will be most remunerative in every respect, for a light and powerful electric accumulator would find a number of applications, the enumeration of which alone would fill a volume.

A method of accumulation brought before the meeting of the British Association in Sheffield, in 1879, by Mr. Ayrton, must also be mentioned here. He proposed to store the work of waterfalls, by decomposing water under pressure, and utilizing the hydrogen thus produced. We find here, in another form, and with the additional principle of compression, the idea which led to the formation of the "Alliance" company, but as it is no longer a question of burning coal in order to produce gases, but rather to utilize natural forces, the question presents itself from a more philosophical point of view.

Induction Coils.—There is no necessity for giving here the history of these apparatus, which have rendered the name of Ruhmkorff celebrated, and have earned for this learned and unpretending inventor a prize of 50,000 francs awarded by the Académie des Sciences.

An induction coil is nothing else but an electric transformer, receiving electricity from a battery, and transform-

ing it into electricity of high tension, similar in its effects to the so-called statical electricity. These currents are characterized by their high tension on the one hand, and by their feeble intensity, or quantity, on the other. That explains why these currents, although capable of overcoming great resistance, can only act very feebly when traversing electro-magnets in which the magnetic action is a function of the intensity of the current, unless these electro-magnets are surrounded by a very fine and very long wire.

The various applications of the Ruhmkorff coil are well known, as for the firing of mines and of torpedoes, its application in medicine, the lighting of Geissler's tubes; its use for physical experiments, etc.

This interesting apparatus can, therefore, no longer be considered as a new application of electricity, but we must nevertheless mention here an induction coil remarkable for the effects which it produces, and which is probably the most powerful one constructed up to the present.

Spottiswoode's Induction Coil.—Mr. William Spottiswoode, late President of the Royal Society, has had constructed by Mr. Apps an induction coil of remarkable power, which has given sparks 110 centimetres long. The noise produced by each spark is like the report of a pistol.

The general view of the instrument is represented in Fig. 51. The coil is supported by two massive wooden pillars, covered with indiarubber and coated with paraffin at their two extremities. Besides these two supports, there is a third in the middle, whose height can be regulated by means of a screw, in order to resist the bending of the principal piece.

The coil can act with two induction circuits used alternately. Two persons can remove the one and substitute the other for it in a few minutes.

The first, which is used for long sparks, and in fact for

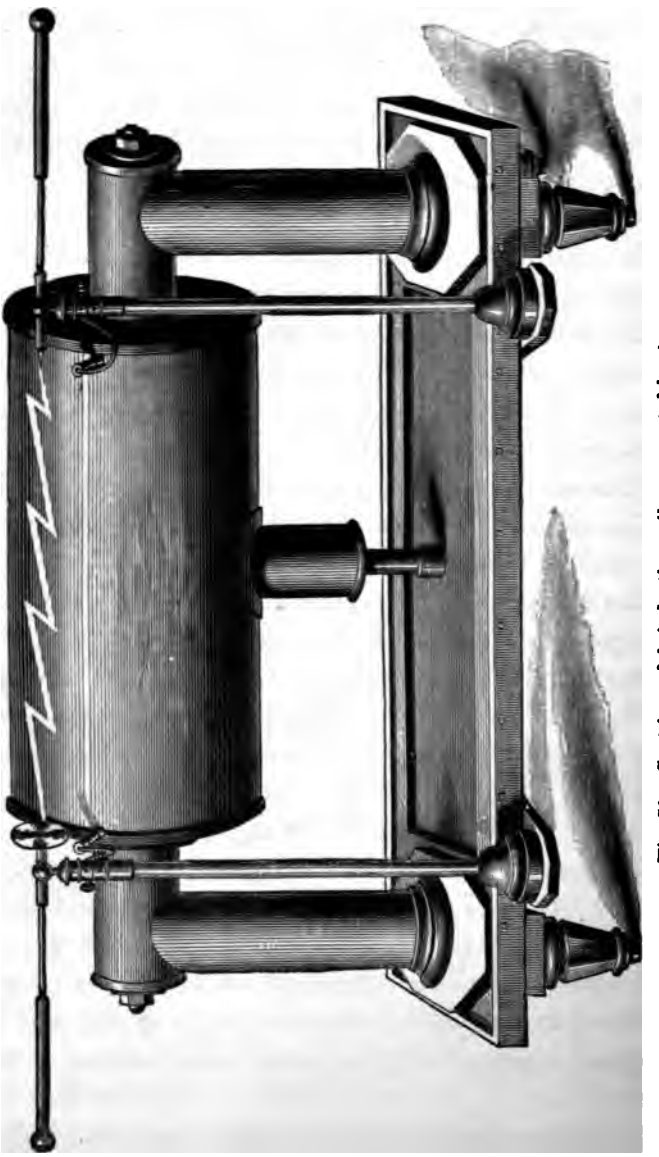


Fig. 51.—Spottiswoode's induction coil, constructed by Apps.

most of the experiments, has a core composed of a bundle

of iron wires of $\frac{8}{10}$ of a millimetre each, and forming together a cylinder of 1·1 metre in length and nine centimetres in diameter. It weighs more than 30 kilogrammes. The copper wire constituting the inductor has a length of 600 metres, a diameter of 2·23 millimetres, a conductivity of $\frac{93}{100}$, a total resistance of 2·3 ohms, and weighs about 25 kilogrammes. It is wound round the bundle of iron wires in 1344 spirals, which are arranged in six layers, and finally presents the form of a cylinder of 1·06 metre, and of an exterior diameter of 12 centimetres.

The other system of induction which is intended for batteries of larger surface, and to give shorter and broader sparks for experiments with the spectroscope, has a core of iron wires of $\frac{8}{10}$ of a millimetre, like the preceding ones, joined together, and forming a cylinder of 1·11 metre long and 97 millimetres wide. The weight of this core is 41 kilogrammes. The copper wire is the same as in the first circuit of induction. The conductor, which is 459 metres long, is composed of two parallel wires. It is divided into three sections of two layers each; their resistances are 0·181, 0·211, and 0·231 ohm respectively. The length of the cylinder composed in this way is 1·01 metre, and its diameter 14 centimetres. The weight of the wire is 38 kilogrammes. Thanks to a new arrangement, these three sections can be joined for one single series, which gives a conductor of 4·87 millimetres diameter, or they can be placed on a shunt, which gives the equivalent of one single conductor of 14·63 millimetres diameter.

This conducting wire has given sparks 86 centimetres long (in the air, with a Grove battery of ten elements, whose platinum electrodes were 76 millimetres by 159).

The secondary circuit is composed of 450 kilometres

of wire forming a cylinder of 95 centimetres in length, 50 centimetres exterior, and 24 centimetres interior diameter. The conductivity of this wire is 94 per cent., and its total resistance 110,200 ohms. It is divided into four sections; the wire of the two middle sections has a diameter of about 0·24 millimetre, whilst in the two exterior sections its diameter is 0·28 and 0·29 millimetre respectively. The reason why the diameter of the induced wire is larger towards the extremities than towards the centre is the accumulated charge which these parts of the conductor have to support. Each of these sections is itself composed of flat discs, which have a thickness of about 200 layers of the wire of which they are formed. Finally, the total number of spirals in the induced circuit amounts to 341,850.

It will be easily understood why such a great length of wire is required on considering that the exterior spirals are nearly a metre and a half long. It is admitted that the spark grows rather with the number of spirals than with the length of wire, provided that a good insulation is ensured in all the parts. To make sure of the result, each disc was separately and carefully tested; then they were tested in series, and all the results carefully registered. As a conclusive test, the coil was charged with seventy Grove elements, without interfering with the insulation.

The condenser belonging to this coil is much smaller than might be expected. After numerous experiments, Apps fixed upon a dimension which is used for coils giving a spark of 25 centimetres. These condensers are formed of 126 sheets of tinfoil, 45 centimetres long by 21 centimetres wide, which are separated by a double thickness of varnished paper, and measure altogether 0·28 metre.

The following are some of the results obtained with this powerful apparatus (the first system of induction being used) :—

With five large Grove couples, the spark reached a length of 71 centimetres;

With ten couples, a length of 81 centimetres;

With thirty couples, a length of 106½ centimetres was obtained.

In some cases even 109 or 110 centimetres were obtained.

It is well known that an induction coil gives two induction currents—one at the moment of the closing of the inducing circuit, the other at the moment of breaking this circuit. The former possesses no tension; it is the second which produces the spark. Experiments made with the handsome apparatus mentioned have proved that the tension of the former can increase to such an extent that sparks of thirty-one millimetres are obtained by it.

This fact, without precedent, deserves the greatest attention. The length of the spark of the current, obtained by closing the circuit, naturally depends on the intensity of the current of induction, and increases with it.

Flint-glass of seventy-five millimetres thickness has been pierced by this apparatus, without even using batteries which give the maximum effect.

Continuous High-tension Currents.—Induction coils furnish a current of very high tension, but intermittent and alternating, or, to speak more accurately, they furnish two perfectly distinct kinds of currents: the closing current, having little tension and much relative quantity; followed by an induced breaking or opening current, having an enormous tension, but much less quantity.

Fig. 52.—Gaston Planté's secondary batteries, arranged for observing the phenomena produced in liquids by high-tension currents.

In certain experiments it may be desirable to have a continuous high-tension current.

Warren de la Rue has solved the problem by using 11,000 elements of his silver chloride battery, which has been described on p. 29. But the resistance of these elements is rather large, and, on the other hand, 11,000 elements occupy a certain space and represent a considerable sum of money.

Gaston Planté, who has made a number of the most interesting researches on high-tension currents, has used secondary batteries of 200 to 800 elements, and has obtained at the outset an effect equivalent to that of 300 to 1200 Bunsen elements. The tension of each couple, which always exceeds two volts, reached 2·8 volts at the beginning of the discharge; it is clear, therefore, that 800 secondary couples can furnish, within a very small compass, a tension superior to that of 2000 Daniell elements, and also of very superior quantity.

Fig. 52 represents an arrangement of 400 elements, divided into ten batteries of forty couples. Two Bunsen couples are sufficient to charge each group for quantity; then, by means of a special commutator, they are grouped for tension, to effect the discharge. In a few seconds the work of several hours of the two Bunsen elements is expended, and this will explain the intensity of the effect.

These experiments, where the current possesses both tension and quantity, are very dangerous, and the apparatus must be handled with the greatest care. Planté received one day the discharge of 600 couples, and he describes the sensation as if a burning iron had been passing through his whole body. Fortunately, this accident had no fatal consequences; but, adds Planté, "it might have

were otherwise if the 800 secondary couples had been in action at that moment.'

Planté's Electric Machine—It has been mentioned that Planté had obtained tensions of more than 2000 volts with 500 secondary elements. These results even have been surpassed, and the electric machine enables us more simply to transform the force of the voltaic battery and to obtain a tension equivalent to that of apparatus of statical electricity. We again give his own account of the invention and construction of this interesting electric transformer—

'Having observed how easy it was to rapidly charge, with a battery of 800 couples, a condenser with a sufficiently thin insulating plate of glass, mica, indiarubber, paraffin, etc., I joined a certain number of condensers made in preference of mica covered with tinfoil, and arranged them like the couples of the secondary battery itself, so as easily to charge them in quantity and discharge them in tension.

"All the pieces of the apparatus must of course be carefully insulated. The commutator consists of a long cylinder Q T (Fig. 53) of hardened indiarubber, and is provided with longitudinal metallic bands, which unite the condensers for surface; copper wires, bent at right angles at their extremities, at the same time traverse the commutator to associate the condensers for tension. Thin plates or metallic wires in the shape of springs are in contact with the two armatures of each condenser, and fixed to an ebonite plate on each side of the cylinder, to which a rotatory motion can be imparted.

"If the two terminals of the apparatus T and T' are connected with a battery of 800 couples, by means of the

conductors P and P′, even several days after having been charged with two Bunsen elements, and the commutator set

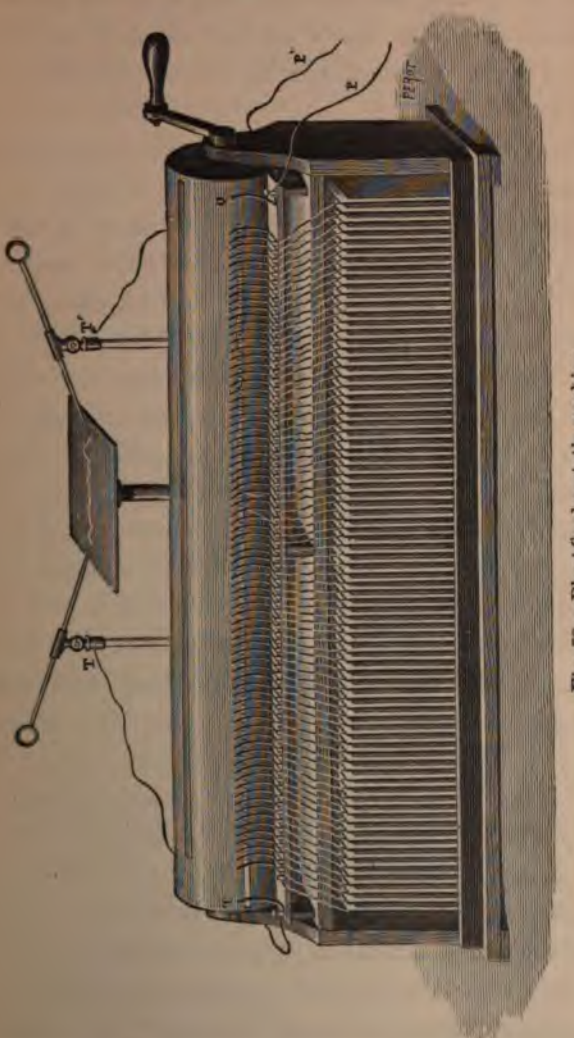


Fig. 53.—Planté's rheostatic machine.

in motion, there appear, between the branches of the charging machine which are coterminous to the armatures

of the last condensers, a number of sparks, similar to those of an electric machine which is provided with condensers.

"By using an apparatus consisting of thirty condensers only, each of which has a surface of three decimetres square, I have obtained sparks of four centimetres in length.

"This apparatus gives favourable results with less than 300 secondary couples: 200 couples gave a spark of eight millimetres, and, by diminishing the thickness of the insulating plates, and increasing the number of condensers, results might be obtained with an electric source of even smaller tension.

"It ought to be understood that the discharges of statical electricity in the apparatus are not alternately positive and negative, but always take place in the same sense, and that the loss of power resulting from the transformation must be less than in an induction coil, for the voltaic circuit does not close upon itself for a single instant, and there is consequently no conversion of a part of the current into caloric effect. The apparatus can be kept in motion, and can produce a considerable number of discharges, without sensibly weakening the secondary battery.

"This is explained by the fact that each discharge only uses up a very small quantity of electricity, and that the circuit of the battery is not closed by a conductor. The electricity of the source simply spreads over the polar surfaces of the condensers while they are discharged. But this emission, which is constantly repeated, must finally carry off a certain quantity of electricity, and when the instrument is charged with a secondary battery, it seems quite possible at length to exhaust, in the form of statical effects,

the limited quantity of electricity furnished by the current of the battery.

"The transformation of dynamical electricity is thus effected by another method than induction properly speaking, simply by a protracted statical effect, and this apparatus is properly designated by the name of 'rheostatic machine.'"

After having enumerated the different methods by which electric currents are produced and transformed, we now pass to the description of some of the interesting applications of this mysterious force.

PART II.

ELECTRIC LIGHTING.

ELECTRIC lighting, both as regards its past history as also its future, ranks first among the applications of electricity, although several of these applications have been developed to a much higher degree.

The voltaic arc was first produced by Sir Humphry Davy, in 1813, with a battery of 2000 zinc and copper elements; but it was not till 1842 that Deleuil's and Archereau's experiments foreshadowed the possibility of its use as a source of lighting.

At that time the only batteries known were hydro-electric batteries; electro-dynamic machines were still in their infancy, and the means for regulating the light more than primitive.

In 1857, the Alliance machines, perfected by Van Malderen, showed that electric light could be advantageously produced in certain special cases, and the application of these machines for lighting the lighthouses of La Hève, as early as 1863, brought the electric light for the first time within the reach of practical questions.

The invention of the Gramme machine in 1870 gave a new impetus to the electric light, which up to that time had

only found a limited number of applications; and finally Jablochkoff's discovery, in 1876, brought prominently to the front a new system of lighting, which is destined, not so much to do away with gas altogether, as to replace it in a great number of applications where the electric light has properties which recommend it in preference to all other systems.

After having described the different modes of production of electric light, certain applications will be mentioned where electric lighting has from the outset superseded gas; not that this latter will ever be completely ousted from its position as a lighting agent by this new discovery.

Modes of Production of Electric Light.—All electric lighting depends on two essentially different factors—

1. The electric generator.
2. The electric lamp.

After having considered the different methods used for the production of light, it will be easier to appreciate the value of the different sources of electricity with regard to the apparatus they are intended to supply. All the electric generators in use at the present time have been described in the first part of this work, and we shall refer our readers to the respective paragraphs whenever occasion requires.

The fundamental principle of the production of light in any system whatever, whether with oil, petroleum, gas, or electricity, is the following:—To bring a solid, liquid, or gaseous body to a high temperature, the quantity of light produced being the greater the higher the temperature of the body. In all lighting the rise of temperature is produced by the combustion of the oil, petroleum, or gas, which respectively supply the focus of light. The high temperature of the luminous part of electric light is produced by

the current passing through a medium which offers resistance to electricity; the electric current is thereby transformed into heat, within a very narrow space, by heating a relatively small number of molecules. When the electric current heats a gaseous conductor, the light thus produced is called the voltaic arc. This voltaic arc, however, only becomes very luminous when the gaseous conductor contains solid particles detached from the electrodes; these particles are raised to a very high temperature, and impart to the conductor its characteristic dazzling light. Conductors of gas carbon, or very dense carbon, are used for this purpose. The heat given off by the combustion of this carbon, in addition to that of the current, favours the production and preservation of a high temperature, and contributes in no small measure to the brilliancy of the light.

If a solid conductor of feeble conductivity is heated by the current and rendered luminous, the light in that case is produced by incandescence. Thus we have two distinct methods for the production of electric light, which we are going to examine successively.

The Voltaic Arc.

Whatever may be the tension of the electric source, it never is sufficient to cause the light to pass between the two electrodes, unless they are previously brought into contact. At that moment, the gas surrounding the electrodes is heated by the current, it becomes a better conductor, and the contact between the electrodes can now be broken, the passage of the current through the gaseous conductor being maintained all the while.

With high-tension currents, like those of Holtz's machine,

and induction coils, the discharge can take place between two electrodes at a certain distance, and electric light is produced, but unfit for lighting purposes.

In an interesting historical essay on the light produced by electricity, published in the French journal *La Nature*, in April, 1878, M. Antoine Bréguet ascribes to Otto von Guericke (1602–1688), Mayor of Magdeburg, the first light produced by electricity.

In a paper read at the Royal Society, on the 6th of February, 1746, Dr. Watson pointed out that electric sparks seemed to be of different colours according to the nature of the substances from whence they sprang—that the light seemed much redder when coming from substances with a rough surface, like rusted iron, oxidized copper, etc., than from substances with a smooth surface.

It was Watson who first made use of the electric light for lighting purposes; with four of his apparatus he obtained such large jets of flame, and so close to one another, that in a dark room the faces of thirteen persons present at the experiment could be distinctly seen.

All these experiments were made with statical electricity obtained by friction machines. The discovery of Volta's pile brought with it the realization of a powerful electric light—of the voltaic arc, properly speaking.

Sir Humphry Davy obtained by means of a battery of 2000 elements, of an active surface of more than eighty square metres, the poles of which were connected with two carbon ends, a dazzling and continuous light, without any perceptible noise.

Why cannot friction machines, which give a spark, give an intense light like batteries or electro-dynamic machines?

This question is easily answered by referring to what has been said about quantity and tension of electric currents.

The current of a battery generally presents great quantity and feeble tension, whilst electricity produced by a friction machine with a glass or ebonite disc, has on the contrary an enormous tension and small quantity.

The great brilliancy of the voltaic arc is due to particles of the material of the poles being raised to white heat in their passage from one pole to the other; it is clear, therefore, that a slender spark, which carries with it but very few particles from the electrodes, must be much more exposed to the cooling influence of the ambient air.

In 1850, Professor Masson, of the École Centrale, made numerous experiments on the voltaic arc, and showed that electricity produces no current in an absolute vacuum, which bears out the assumption of a ponderable matter, the nature and density of which greatly affect the tension of the electric fluid necessary for the production of a current. He proves that the electric spark is produced by a current, and propagated through the ponderable matter, which is heated by the spark in the same manner and according to the same laws as a voltaic current heats and renders luminous a metallic wire.

Matteucci, about the same time, investigated the conductivity of the arc passing between points of various substances, and found that it depended less on the conductivity of the metals forming the points than on their fusibility and volatility.

He also remarked the difference of temperature of the two poles; this difference increases with the non-conductivity of the materials the poles are made of, and also with

the readiness with which these materials are dissociated or burned.

The great difference of temperature between two carbon points is chiefly due to the unequal heating of the two poles, the positive pole being nearly twice as hot as the negative one; this unequal heating is accompanied by a difference in the disintegration of the substance, and this circumstance can, in its turn, modify the electrical resistance and the heat produced. The length of the arc varies with the tension of the current,—it can reach four to five centimetres with appropriate currents; its shape also depends on its length. When the arc is short, it resembles a condensed sheaf of luminous threads, generally assuming a cylindrical shape.

A more rarefied atmosphere of violet colour surrounds this first sheath like a case, and the base of this annular cylinder is enlarged on the positive carbon, whilst its opposite part is extinguished on reaching the negative pole. If the voltaic arc is lengthened, the sheath becomes less condensed and more slender, and the violet sheath surrounding it assumes more the appearance of a flame. The central part is composed of incandescent particles, which detach themselves from the melted extremities of the points, seem to attract one another, and to form a continuous chain between the points. The exterior part of the arc consists of even more finely divided matter.

Fig. 54.—The voltaic arc.

In the air, the voltaic arc rapidly but unevenly consumes

the carbons, in the proportion of about one to two. The result of this uneven combustion is that the luminous point is displaced, and that the electrodes become deformed; the negative pole presents a sharp point, while the positive pole assumes a hollow, crater-like shape (Fig. 54), and surrounds the luminous point with a more or less conspicuous border.

These phenomena are produced with continuous currents. With alternating currents, the waste of the carbons is even and regular; both extremities assume a pointed shape, and the luminous point is thereby more completely disengaged.

It would, however, be a mistake to consider the crater-like shape of the luminous point as an inconvenience, for the hollowed electrode acts in this case as a reflector, and when the lamp is placed sufficiently high, the floor receives a larger quantity of light than the ceiling, which is a great advantage.

For the lighting of lighthouses, the decidedly concave shape of the positive electrode can supply, with a convenient arrangement of the negative carbon, a light emitted with much greater intensity in a given direction; continuous currents are, therefore, in this country preferred to alternating currents for the lighting of lighthouses.

The light thus produced is called condensed light; it is obtained by placing the lower negative carbon in such a position that its axis is in the prolongation of that side of the upper carbon which faces the horizon that is to be lighted. By this arrangement, if the light produced by the carbons is 100, the following intensities are obtained in different directions :—

In front	287
On each side	116
Behind	38

According to the different applications, it will therefore

[illegible] light of ordinary

[illegible] are three

[illegible] the apparatus [illegible] have been

[illegible] It will be [illegible] that it is not [illegible] and that on [illegible]

[illegible] between the two [illegible] the regulators of the [illegible] various causes,

Jacques Foucault—[illegible] first observed [illegible] diminished in water [illegible] was extremely rapid, and [illegible] the electric [illegible] great progress was made [illegible] the carbon left [illegible] This carbon [illegible] which fuses, vaporizes, [illegible] the steadiness of the flame.

In 1842 Bunsen [illegible] obtain hollow cylinders of [illegible] carbon for his nitric acid batteries: for this purpose he cast a mixture of dry pulverized tar and glue into moulds, and baked them. He obtained thus a porous carbon cylinder of little compactness. To remedy this latter defect, he dipped the cylinder into treacle, and baked it a second time; the sugar stopped up the pores, and left a very pure

and compact carbon behind. The operation was repeated as long as there were any holes left, and till a faultless cylinder was obtained.

In 1846, Staite and Edwards took out a patent for a similar method of fabrication, specifying the use of these carbons for the production of the voltaic arc.

In 1849, Le Molt patented a composition, formed of two parts of gas carbon, two parts of wood charcoal, and one part of liquid tar, the whole well powdered, mixed, compressed, moulded, soaked in treacle, baked for twenty-four hours, and purified by immersion in acids.

In 1852, Watson and Slater prepared carbon from the charcoal of twigs, which was purified with lime, baked, dipped in a solution of alum, baked again, soaked in treacle, and baked a third time.

In 1857, Lacassagne and Thiers dipped pieces of gas carbon into a solution of caustic potash or soda, which had previously been fused to transform the silica into soluble silicate. By washing the carbon sticks afterwards with hot water, and exposing them to a current of chlorine at red heat, compounds which had not been acted on by the potash were transformed into volatile chlorides of silicon, potassium, iron, etc. The light obtained with these carbons is a little steadier, but they produce a great deal of ashes and flake.

By using very pure materials, and forming his carbons with tar that had been distilled a second time, Jacquelain obtained plates which, when cut into sticks, gave a white, steady light, whose intensity, for equal currents, surpassed that of the ordinary carbons by twenty-five per cent.

In 1877, Archereau made excellent carbon points from compressed carbon mixed with magnesia.

[illegible]

[illegible] and [illegible] is tritu- [illegible] pressure [illegible] are [illegible] again, [illegible] times. [illegible] it [illegible] and with or giving [illegible]

[illegible] in the manu- [illegible] by the destructive [illegible] behind [illegible] The [illegible] by a hydraulic [illegible] that the [illegible] 103 gas- [illegible] Arbleaux carbons equal [illegible] gave a light equal [illegible] gave from 200 to 210 [illegible] source, and also [illegible]

The most remarkable at the present moment are Carré's carbons. He supplies very smooth and very straight sticks of all dimensions from one to twenty millimetres in diameter. Cylindrical carbons are now almost exclusively used; their dimensions vary with the system of lighting.

In Reynier's incandescent lamps sticks of two to three millimetres are used; with Werdermann's lamps, Jamin's and Jablochkoff's candles, carbons of four to five millimetres. The carbon pencils employed in the Brush lamp are a foot long, and are electroplated with a thin covering of copper and last about eight hours, during which time about nine and a half inches of the positive and about four inches of the negative carbon are consumed. In regulators fed by Gramme's machines or machines of similar power, carbons of seven to ten millimetres are used. Finally, for the powerful regulators for lighthouses and other naval purposes carbons are used whose diameter sometimes reaches twenty millimetres.

Classification of Apparatus for Electric Lighting with the Voltaic Arc.—The number of apparatus for the production of the voltaic arc, and which enable us to regulate more or less accurately the distance of the carbon points, and the steadiness of the arc, is so considerable that it is impossible to establish an exact and complete classification. They can, however, be divided into two large classes, according to the relative position of the carbons—

1. Electric lamps, or electric regulators.
2. Electric candles.

In the electric lamp, the arc is produced between two carbon points, placed end to end, by a self-acting apparatus, which also keeps the points at a convenient distance.

Electric candles are apparatus in which the carbons are placed parallel to each other. They differ from the lamps by the complete absence of any mechanism, or by a mechanism the simplicity of which constitutes in practice no slight advantage.

CHAPTER I.

ELECTRIC LAMPS, OR REGULATORS.

Hand-worked Regulators.—The light produced by the voltaic arc received no practical application till 1844; up to that time it was only considered an interesting lecture experiment and nothing else, for neither powerful batteries nor proper carbons were then obtainable.

In 1844, Léon Foucault used the Bunsen battery, which had just been invented, and replaced the sticks of common charcoal, which had been in use since Davy's time, by pieces of gas carbon.

He constructed a very simple lamp, worked by the hand, which enabled him to take photographs; whilst at the same time Deleuil made public experiments, by the same process, on the Place de la Concorde, at Paris. It is evident that the method of regulation by hand is as barbarous as it is primitive; it is quite obsolete now.

Regulators with Circular Electrodes.—It is worthy of note that the first self-acting apparatus had circular carbons, which are very rarely used now. We shall only say a few words about them.

Thomas Wright, of London, constructed in 1845 a self-acting lamp, in which the arc passed between discs, bevelled on their circumference, and which was set in motion by a special mechanism.

In 1844, Le Molt, a French physicist, patented a similar apparatus, which acted for twenty or thirty hours without necessitating any adjustment of the lamp.

In 1857, Harrison constructed a self-acting regulator with voltaic arc, in which there was a single circular electrode placed in the lower part, and connected with the negative pole of the electric source; the positive electrode consisted of a carbon pencil fixed to a spiral metallic tube, which advanced by means of clockwork in proportion as the carbon was used up.[1]

In 1877, Reynier invented an apparatus in which the carbon discs are carried by two systems of articulate levers, isolated from one another, and set in motion by two independent clockworks. The distance of the points is regulated by the action of a solenoid, and the discs move slowly under the action of a clockwork movement, to present successively all the points of their circumference to the focus of light. This regulator has been tried at the Gare du Nord, Paris, and at M. Bréguet's house, where it has given good results; it is, however, too complicated. The carbon discs, moreover, throw too much shade, and have therefore been replaced by carbons of the shape of square or round sticks.

Regulators with Oblique Carbons.—They were first constructed in 1846, by William Edwards Staite. The two carbons were inserted in two directing sheaths, and descended in proportion to their waste by means of springs, and finally came to abut against a refractory non-conducting substance. The length of the voltaic arc is altered by displacing one of the carbons.

Rapieff's Lamp.—This lamp, invented in 1878, consists

[1] See *L'Éclairage à l'Électricité* of H. Fontaine, 2nd edit.

Fig. 66. Rapieff's electric lamp.

of four carbons two for each pole.

The upper pole consists of two carbons of a diameter of six millimetres, sliding between rollers, which direct their motion and establish a perfect electrical contact. These two carbons form a sort of V, the length of which diminishes with the combustion, whilst its meeting point is fixed. A weight, attached to a string, as will be seen from Fig. 55, causes the carbons to descend; the meeting of the points causes the carbons to stop, and fixes the luminous point.

The lower pole forms a reversed V, lying in a plane perpendicular to that of the carbons of the upper pole. The same arrangement of rollers and strings with weights, raises the carbons which, by their meeting, afford a second fixed point as regards their support. This support, which is articulated at the point O, is destined to maintain the carbons at a

proper distance at the moment when the current passes. To obtain this result, a flat electro-magnet with two branches is contained in the socket; one of these branches is fixed, and the other articulated at one of its extremities. At the moment when the current passes, the opposite poles attract one another, and the displacement of the lower movable branch of the electro-magnet acts on a rod contained in one of the vertical supports of the apparatus, and causes a contraction of the support of the lower carbons; a withdrawal of the carbons which had originally been in contact, ensues, and consequently the formation of a voltaic arc,

Fig. 56.—Rapieff's lamp (socket of the apparatus).

whose length is regulated by counteracting the effect of the electro-magnet by a spiral spring; a regulating screw keeps this spring properly adjusted. By this simple arrangement, an electric lamp is obtained in which the luminous point remains constant, and the carbons are of unlimited length; the resistance, moreover, which these carbons introduce into the circuit is very feeble, and independent of their length. In another arrangement,

Rapieff replaces the two carbons of the upper pole by a single carbon of larger size. In this lamp with three carbons, the part of the electro-magnet is reversed: it only tends to bring the carbons into closer proximity for the purpose of lighting them. When the lamp is lit, this electro-magnet ceases to act; the arc has then a constant length, which is regulated in advance, and only depends on the number of apparatus introduced into the circuit.

Each lamp is supplied with an ingenious contrivance to which Rapieff has given the name of safety apparatus, and which re-establishes the circuit directly between the borders of the lamp, if from some reason or other—for instance, by the accidental breaking of a carbon—the lamp is rendered useless. The Rapieff system is used in London for the lighting of the *Times* printing-office. A Gramme's machine with alternating currents (type of sixteen candles), of whose four circuits two only are utilized, sends its current into two series of three lamps each. These lamps light up most brilliantly a surface of about 400 square metres, in spite of their opaque glass globes.

Rapieff's lamps are always used with alternating currents; they allow, to a certain degree, a division of light, since four of them can be placed in tension on a single circuit.

Gérard's Lamp.—In 1879, Anatole Gérard, a Paris engineer, constructed a lamp similar to Rapieff's; it differs from the latter by the method of its lighting. The four carbons, arranged in groups of two, are placed above the luminous point, and descend by their own weight without the aid of strings. An electro-magnet with a very fine wire, mounted on a shunt of the lamp circuit, brings the carbons into that proximity which is necessary for the lighting of the lamp: for at the moment when the current

is sent into the whole apparatus the carbons do not touch, and the whole current passes into the electro-magnet; but when once the light is produced, the electro-magnet ceases to act, for it only receives a very feeble part of the current.

Gérard uses alternating-current machines for his regulators. Siemens' machine with eight coils can feed four lamps of about a hundred Carcel burners each.

Regulators with Solenoid Action.

These are the first self-acting regulators which have been constructed. The oldest, which dates back as far as 1848, was constructed by Archereau, whose primitive apparatus has served as a basis for numerous other combinations.

Archereau's Regulator.—In Archereau's apparatus, the upper (positive) carbon is fixed, the lower (negative) carbon rests on a cylinder made half of iron and half of copper. This cylinder is placed in a solenoid, which is traversed by the current, and is kept in equilibrium by a counterpoise. The action of the solenoid produces and maintains the distance of the two carbons by exercising a magnetic attraction on the iron rod which terminates the negative carbon, provided the proportions between the power of the solenoid, the weight of the rod, and the intensity of the current are carefully established. Archereau's regulator is no longer used now, because the luminous point did not remain constant, and, on the other hand, because it was rather difficult to regulate the action of the solenoid without causing a rupture of the arc.

Jaspar's Regulator.—In this apparatus, the carbons are

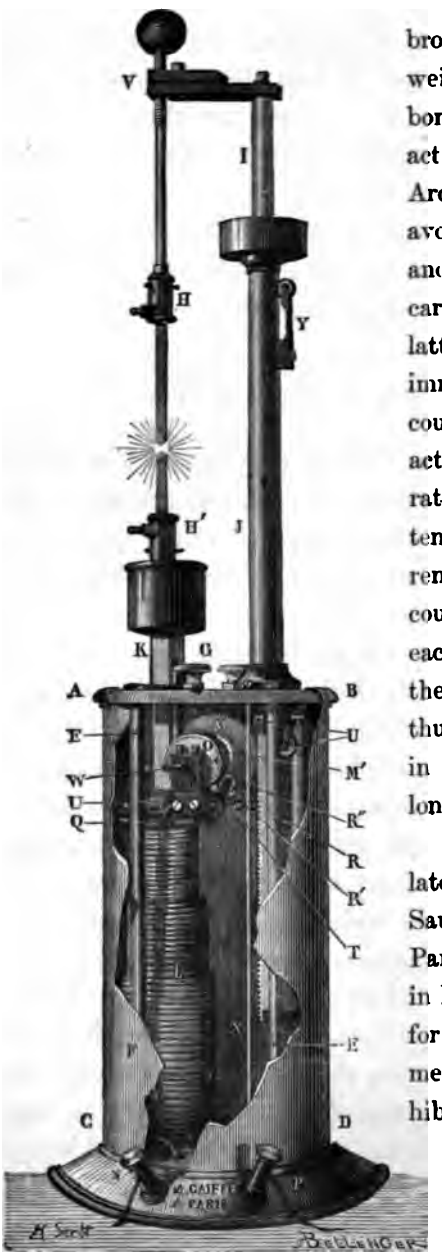


Fig. 57.—Gaiffe's regulator.

brought together by the weight of the positive carbon, and kept apart by the action of a solenoid as in Archereau's regulator. To avoid sudden movements, and give to the negative carbon a good contact, this latter carries a lateral stem immersed in mercury. A counterpoise with variable action regulates the apparatus according to the intensity of the passing current. Another movable counterpoise regulates at each moment the action of the movable weight, and thus prevents any change in the length of the arc as long as the carbons last.

This very simple regulator is used at Messrs. Sautter and Lemonnier's at Paris, at the Gare du Nord in Brussels, and has gained for its inventor a gold medal at the French Exhibition of 1878.

Gaiffe's Regulator.—In Gaiffe's regulator, the action of the solenoid is produced

in a somewhat different manner from the preceding ones. The carbon-holders H H′ are exactly counterbalanced with regard to their weight, which in no way affects the function of the apparatus; their sliding motion is rendered very easy by means of a quadruple system of rollers U, which prevent all direct friction. The motion of the carbons is effected by the detent of a spring contained in the drum O, and by the help of two wheels M M′, of different diameter, which transmit their motion to two rack-works K and I; the two carbon-holders H H′ are in direct connection with K and I. In its movement, the rod of soft iron penetrates more or less into a coil L, which is surrounded by an insulated spiral wire. The attraction of this spiral coil on the iron rod causes the necessary distance of the carbon-holders for the production of the luminous point.

The spiral coil and the spring of drum O are arranged in such a manner that their antagonistic forces remain in the same relation during all the time that the carbon-holders are moving; consequently, if the voltaic arc has a length of three millimetres, for instance, at the moment of the lighting of the regulator, it will have the same length at the time of extinction caused by the waste of the carbons. The spring can be stretched more or less, and the apparatus can therefore be used for very different intensities of currents; its action is sufficiently regular with a Bunsen battery of from fifteen to twenty elements. By a special contrivance, the luminous point can be displaced at will, without being obliged to extinguish the apparatus or otherwise to interfere with the carbon-holders. This contrivance consists of a system of pinions R, R′, R″, which under ordinary circumstances are kept apart from the wheels M M′, but can be

made to work into these wheels by a slight pressure, so as to allow, by the help of a key, of a simultaneous raising or lowering of the carbon-holders without altering their distance. The luminous point can thus be easily regulated —an indispensable requirement for optical experiments and for projections.

The apparatus is worked in the following manner:—The current enters by the terminal P, follows the path X, J, I, V, H, H', K, passes into the coil L, and leaves by the terminal N. When no current circulates, the two carbons press against one another by the action of the spring of drum O; but as soon as the electric circuit is closed, the coil attracts rod K, and the combined movement of rod K and the second rod I brings about a withdrawal of the carbons and the formation of the voltaic arc. The attractive force of the coil must always be slightly superior to the action of the antagonistic spring; this condition is fulfilled by loosening or tightening the spring.

Reynier's Regulator with Spring and Solenoid.—Numerous experiments made by Saint-Loup and Reynier show that the attraction exercised by a solenoid on a bar placed along its axis can be depicted by a curve which, if the distance of the soft iron from a fixed point be represented by the abscissæ, and the magnetic attraction by the ordinates, starts from a point above the axis of x, and attains its maximum height when the lower end of the bar is at two-thirds the height of the core, and from this point falls back to the axis of x. The descending portion of this curve deviates very little from the straight line joining its extremities.

The diagram of a spiral spring which unwinds on lengthening has the same form; in order to get a spring

whose diagram coincides with that of the solenoid, it suffices that, when the spring is subject to a weight equal to the maximum attraction of the solenoid in question, it should be shortened by an amount which is equal to the length of the path traversed by the soft iron between the position corresponding with that maximum and the position where the magnetic attraction ceases.

A spring of this description, placed beneath the soft iron in the solenoid, and whose lower end is at a point determined by the coincidence of the diagrams, forms with the bar a system which enjoys the following advantages:—

1. When the current which magnetizes the solenoid is of normal intensity, the spring counteracts the magnetic attraction which draws down the soft iron, whatever may be its position above the region of maximum attraction.

2. When the current is less intense, the action of the spring overcomes the magnetic attraction, and pushes the iron upwards, whatever its position.

3. When the current has greater intensity, the attraction overcomes the action of the spring, and draws down the iron, whatever its position.

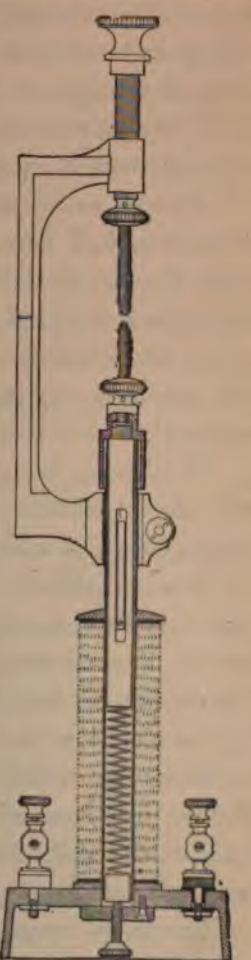


Fig. 58.—Reynier's lamp, with voltaic arc.

A solenoid, a soft iron rod, and a spring combined under the conditions that have been described, form the principal parts of the lamp. The lower carbon-holder is mounted on the soft iron, and follows its movements; the upper carbon-holder is immovable and attached to the body of the solenoid by a double-bent support. The lamp (Fig. 58) is represented before it is lit, the iron being slightly above the position of maximum attraction.

As soon as the current passes into the apparatus, the iron is pushed downwards in the solenoid, and descends until the arc reaches its normal length. In proportion as the carbons are used up, the iron ascends in gradual stages, which are equal to the sums of the lengths of the wasted carbons, so as to maintain the length of the voltaic arc constant.

The spring being constructed for a given intensity of the normal electric current, the diagram of the spring no longer coincides with the curve of the solenoid if a current of different intensity passes into the lamp—it will be above or below that curve. This diagram can be brought back to an approximate coincidence by altering its origin, which can be done by loosening or tightening the spring by means of a screw in the socket of the lamp. This adjustment can only be carried out within very narrow limits. The lamp gives a bad result with currents of very different intensity from that for which the spring has been originally constructed.

The lamp represented in Fig. 58 is a laboratory model, specially intended for projections and currents of average intensity. A rougher model still, with larger carbons, is used as a safety-lamp with the self-acting lighting apparatus of the same inventor (*vide* p. 213). It is set in action as

soon as the carbons of the principal regulator are used up, and acts for twenty minutes, which allows time for supplying the first lamp with fresh carbons without interrupting the light. The lower carbon progressing alone, the luminous point rises continually; to counteract this the upper carbon is from time to time pushed slightly forward by turning the screw which supports the carbon-holder, and the light is thereby brought back to a convenient height. During all this time, the lower carbon-holder continues to move, and thus the length of the arc remains constant. Less complete than Duboscq's and Serrin's regulators, but also less costly, this little instrument is sufficient for most of the optical experiments.

Marcus, Dubos, etc., have also constructed regulators with solenoid action, but their description would lead us too far.

Regulators with Motor Springs.

The first of these regulators was invented by Foucault, and afterwards improved by Duboscq, who uses it for his projection apparatus and for lighting the stage. In the original apparatus, the adjustment of the carbons had to be effected with the hand. In the improved apparatus, there are two distinct clockworks—the one for bringing the carbons together, and the other for their withdrawal. An electro-magnet placed in the circuit unclamps one or the other of these mechanisms, according as the current is more or less intense. The luminous point can be raised or lowered during the action—an indispensable requirement for projections—by turning with the hand one of the toothed wheels of a drum, which acts upon the carbons.

This apparatus can be used in all positions, but it is rather delicate, and must be regulated for each special application.

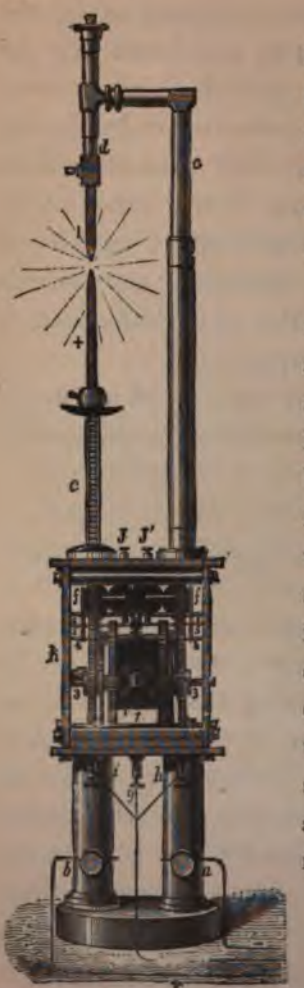


Fig. 59.—Girouard's electric lamp.

Girouard's Electric Lamp with Independent Regulator.—We give a description of this apparatus in the inventor's own words, after a memorandum which Du Moncel read at the Académie des Sciences, on the 24th of January, 1876.

"This new electric lamp has a regulator, which can be placed at a convenient distance from the apparatus in which the electric light is produced, and which can be rendered sufficiently sensitive for all requirements. The lamp therefore, consists, of two distinct apparatus, which are represented in Figs. 59 and 60. They are connected by two different circuits, giving passage to two distinct currents: the one, very strong, produces the voltaic arc after passing through the electro-magnet of the relay; the other, rather feeble, only effects the unhinging of the clockwork which regulates the movement of the carbons.

"The relay consists of an electro-magnet *b* with a coarse wire, the armature *n* being fixed to a lever, which is

pulled in opposite directions by two springs o and o'; it can occupy a definite position, and consequently place a contact spring of the lever between two contact screws p and q, which are in connection with the electro-magnetic systems regulating the movements of the carbons. The tension of the springs o and o' are calculated in such a manner that, for an intensity of current sufficient to yield a good light, the armature in question has no contact with the screws p and q. Hence, if the current becomes too strong or too

Fig. 60.—Relay of Girouard's lamp.

weak, the lever presses on one or the other of these screws and produces an unclamping, which causes an approach or a withdrawal of the carbons. It is clear that, if the carbons are in contact, the light-producing current must be of superior intensity to the normal current of the armature of the regulator; a contact will be established with the screw p, and a withdrawal of the carbons will ensue. On the contrary, if the distance of the carbons becomes too

great, the contact will be effected by the screw *q*; a closing of the current will take place, and consequently an approach of the carbons. A convenient adjustment of the two springs *o* and *o'* and the screws *p* and *q* will render the apparatus as sensitive as could be desired, and enable us to control it from a distance, without the necessity of touching the light-producing part.

"An interrupter permits the closing or the opening of the current which produces the light. The lamp consists, like all ordinary electric lamps, of two long pencils of graphite carried by a rackwork and set in motion by two distinct clockworks, although directed by the same drum. The last movable wheel of each of these mechanisms is stopped by a detent of a particular electric system, which is connected to the screw *p* and the screw *q* of the regulator, and the wheelwork of the two mechanisms is constructed in such a manner that, at the moment of approach or withdrawal, the relative movement of the carbons maintains the luminous point in a fixed position.

"The arrangement of this apparatus, which can be worked in all positions, renders it convenient for a great number of applications—for instance, military operations, for navigation, for lighting the stage, for submarine research, and even for projections in physical experiments. For this latter purpose, there is a small mechanism fixed to the two rackworks, which allows of a vertical displacement of the luminous point without extinguishing the light, and consequently the light can be properly focussed.

"In the model represented (Fig. 60), the battery for charging the electro-magnets of the lamp is enclosed in the socket of the regulator. It is a small mercuric sulphate battery."

Régnard's Regulator.—In this regulator, the carbons are screw-shaped along their whole length, which makes them more expensive; and move forward or backward by the action of two female screws, which are set in motion by a spring and an electro-magnetic loosening apparatus, similar in principle to that employed by Foucault-Duboscq.

Very long carbons can thus be placed in the lamp without increasing the resistance of the circuit, since the contacts take place very close to the arc; but the manufacturing of the carbons presents serious difficulties, and raises their price considerably, and this renders the apparatus of little practical value.

Regulators with a Positive Motor Carbon-Holder.

In most of the new regulators actually in use, the springs and clockwork have been suppressed, by utilizing the weight of the upper (positive) carbon and that of its movable support in order to produce the motion for the approach of the carbons.

Serrin's Regulator.—This regulator has found a great number of practical applications, for it fulfils almost completely, and in a comparatively simple way, all the requirements of an apparatus of this kind.

Serrin's apparatus leaves the carbons in contact when no current passes; when the current is established they are removed to the required distance, and then approach one another gradually without coming again into contact. If the arc is broken by some cause or other—for instance, a strong wind or the breaking of a carbon—the apparatus brings the carbons again into contact, and then removes

them to the necessary distance, so that the voltaic arc is reproduced with all its former brilliancy.

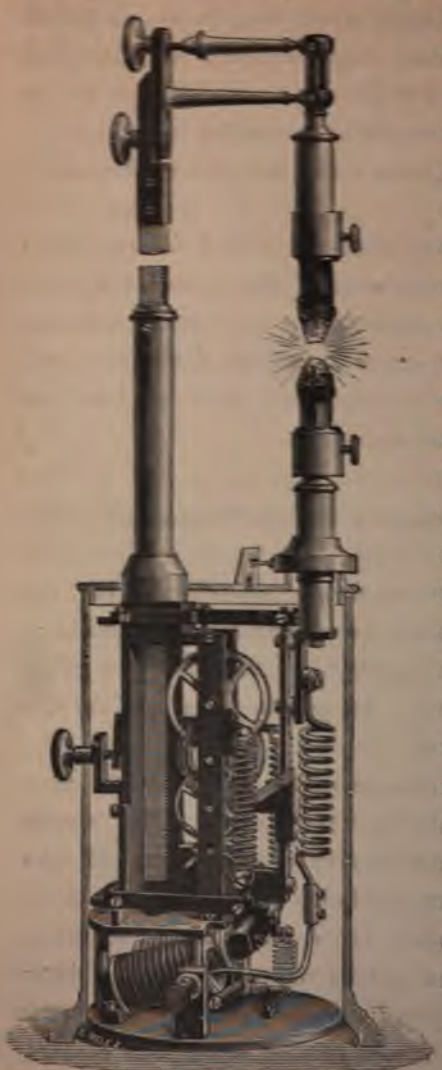


Fig. 61.—Serrin's regulator, constructed by Suisse.

To realize all these conditions, the positive carbon-holder (Fig. 61) consists of a rackwork, acting on a series of multiplying wheels for the increase of speed, the last of which corresponds with a wheel carrying a certain number of long teeth in the form of a star. When no current passes, and the carbons are separated, a motion of the wheels takes place until the carbons touch. At that moment the electromagnet becomes active, attracts its armature, and causes the descent of a movable oblong check to which it is fixed; this catches the toothed wheel, stops the descent of the upper (positive) carbon, and lowers the negative carbon, which is fixed to this movable piece.

If the arc is lengthened, the intensity of the current is weakened, the movable piece ascends under the action of two supporting springs, and sets free the large toothed wheel. The upper carbon can now descend a certain distance, until the arc is sufficiently shortened and the intensity brought back to its normal strength, when a fresh stoppage ensues, and thereby a new state of equilibrium. If, on the contrary, the carbons are too close to one another, the intensity of the current increases, the movable piece is more strongly attracted by the electro-magnet, and continues to descend, producing a lengthening of the voltaic arc. On the left of the diagram is a screw which tightens or loosens the antagonistic spring of the electro-magnet.

In this apparatus, constructed by Suisse, the luminous point is displaced, and descends in proportion to the waste of the carbons. In an improved model, the luminous point remains constant, because the positive carbon descends, and the negative carbon ascends at the same time at a relative rate previously calculated, and which is nearly as two to one.

Serrin's regulators are most frequently used with Gramme's machine (p. 70). The extreme sensitiveness of Serrin's regulator constitutes, under these conditions, an appreciable inconvenience. When the carbons contain impurities, variations are produced in the power of the electro-magnet, which causes an oscillation of the lower carbon-holder. These oscillations increase or diminish the intensity of the voltaic arc, and consequently its resistance.

But as the current produced by dynamo-electric machines varies considerably with the resistance of the external circuit—represented here by the voltaic arc—

variations of intensity ensue from this fact alone, which increase the effect of the first oscillations, and render the light very unstable. Here Serrin's regulator is at fault from the very reason of its excellent qualities.

With regard to this, it must even be remarked that, if the conductors have too great a resistance, the lamps, while giving less light on account of the weakening of the current by the resistance of the circuit, act nevertheless with more regularity.

This arises from the fact that the variations of resistance of the arc, although constant as regards absolute amount, have less influence on the total resistance of the circuit. With a good generator and very pure carbons, these defects can be avoided. From this point of view, Wheatstone's mounting (p. 62) as applied to dynamo-electric machines constitutes a great improvement, which we soon hope to see introduced for Gramme's electric generators, for in machines of that particular description, the variations of the electric elements consequent upon the resistance of the external circuit, are favourable to the regularity of action instead of being opposed to it.

Siemens and Hefner Alteneck's Regulator.—This regulator with motor weight has been constructed with the view of working it with Siemens' and Hefner Alteneck's machines, which have been described on p. 74.

In this continuous-current regulator, the approach of the carbons is effected by the weight of the positive carbon-holder, which serves as motor. The withdrawal, on the other hand, is produced by a small electro-motor, whose action we are going to describe.

The principal parts of this regulator are: The two carbon-holders A and B (Fig. 62), a clockwork movement driven

by the weight of carbon-holder A, and whose last wheel is a ratchet-wheel regulated by a fly I. The current of the machine enters by the terminal C, traverses an electro-magnet E (one of its cores only is represented in the diagram), then passes through the body of the lamp to the positive carbon-holder A, traverses the arc, and returns to the machine by the carbon-holder B, which has an insulated mounting, and by the terminal Z, which is connected with the negative pole.

At the moment when the current is sent into the lamp the carbons are in contact, and the current is very intense; the electro-magnet attracts its cylindrical armature, which is fixed to a large vertical lever, pivoted about Y. This lever rocks from right to left around Y, and a ratchet Q, fixed to its extremity, turns the wheel I by one tooth

Fig. 62.—Hefner Alteneck's regulator with continuous current.

in an inverse sense to the movement of the carbon, but at this moment a contact is produced at X; the current now traverses directly the shunt of feeble resistance produced by this contact, and the electro-magnet becomes inert. Under the action of the spring P, regulated by the screw R, the lever takes up its original position; but then the contact in X is broken, and the magnet is energized afresh: it attracts its armature, and the wheel I turns again by one tooth in a sense favourable for the withdrawal of the carbons. A rapid succession of movements is thus produced, as in the vibrations of an electric bell, and the carbons are very rapidly removed to a normal distance for which the apparatus is regulated. When this distance is reached, the ratchet Q causes a stoppage and maintains the carbons at the required distance. The lever is now close to the contact X, and if the apparatus is well regulated, a sort of vibration is felt on touching N with the finger, which is the safest indication of a good regulation. If the arc is lengthened, the armature tends to withdraw from E, and gets free of the wheel I, which permits an approach of the carbons. Three methods of adjustment are practicable with this apparatus—

1. The tightening of spring P.

2. The distance of the armature from the electro-magnet E, which can be regulated by means of a screw K.

3. The contact X, regulated once for all by the conductor according to the course of the lever and the length of the teeth of the ratchet-wheel.

In practice, by acting on the spring P by means of the screw R, the apparatus gives good results; yet fault will be found with its delicate working and the noise produced by the movements of the lever.

For all that, the apparatus is frequently used in this country and in Germany, like Serrin's regulator is in France.

Carré's Regulator.—In Carré's regulator, which is more especially used with alternating currents, the weight of the upper carbon acts as motor, as in Serrin's apparatus; but the current acts upon a solenoid, containing a soft-iron rod, which is connected with the movement for the withdrawal of the carbons, etc.

Hiram Maxim's Regulator.—The characteristic feature of this apparatus is that the carbons approach one another very quickly when not traversed by a current, as for instance at the moment of lighting, and very slowly when the arc is formed. (See Fontaine's *L'Éclairage à l'Électricité.*) Any sudden approach of the electrodes is thus avoided, and a very steady light obtained.

Burgin's Regulator.—In this apparatus, the withdrawal of the carbons is effected by a framework which carries the lower carbon, and the stoppage by a small brake acting on a pulley of large diameter; this pulley presses against the shoe, and produces the stoppage when the arc has attained its normal length. If the arc is lengthened, the intensity of the current diminishes, the electro-magnet becomes less powerful, the curb is loosened, and the carbons are drawn nearer together. The apparatus is so sensitive that, when the feeding Gramme's machine is set in action by a gas-motor, as for instance Otto's, the movement of the armature of the regulator shows all the variations of speed, at the same time as the intensity of the light increases or diminishes. We shall find still more striking examples of this phenomenon in some of the apparatus for lighting by incandescence.

Dornfeld's Regulator.—The inventor—electric engineer at Messrs. Krupp's, in Essen—has constructed an apparatus similar to that of Bürgin, but in which the descent of the positive carbon is retarded by a fly turning in a bath of mercury; the brake acts by means of a solenoid, which serves at the same time for the stoppage, the release, and the withdrawal of the carbons.

Salignac's Regulator.—The principle applied to this regulator is quite novel and unique. The adjustment of the carbon points is not effected by magnetic attraction as in nearly all other arc lamps, but by the expansive force of a glass stopper placed between two horizontal glass rods, to which the carbons are attached. The two rods, being placed horizontally, are pushed by a spring, and the spark is lighted between them; the glass stopper is heated by the electric light in such proportion that the rods yield gradually to the pressure of the springs and the carbons can approach each other, as is required for the constancy of illumination. The preliminary experiments, which have just been made while we are going to press, are said to have been a wonderful success.

Division Regulators.

All the electric regulators described in the preceding pages do not allow of two apparatus being placed in the same circuit,[1] whatever may be the nature of the electric source—batteries, continuous-current machines, or alternating-current machines.

[1] Rapieff's and Gérard's apparatus must be excepted, for they have an arc of fixed length, so that several of them can be placed on a single circuit provided the tension of the current is sufficiently great.

It is easily explained why such must be the case with all these regulators, for the movement of the carbons is effected by an electro-magnet, which obeys the variations of intensity of the currents which are produced by the lengthening or shortening of the voltaic arc. If two apparatus are placed in the same circuit, the lengthening of one of the two arcs is sufficient to set the two electro-magnets in action, and at the same time to shorten both the voltaic arcs; upon this the second lamp immediately ceases to act, when it is merely a question of regulating the distance between the carbons of the first. In other cases one arc might be very long and the other very short without interfering with the equilibrium, since the intensity of the current will be the same as if the two arcs had the mean length necessary for their efficient working. The connection of the two regulators, therefore, entails in each of them changes which finally result in a complete disarrangement of the whole apparatus.

A number of apparatus have been constructed during the last few years, which render the regulators mounted for tension in the same circuit absolutely independent of each other, and which solve to a certain extent that important problem—the division of electric light. All the regulators used for this purpose are founded on the laws of shunted currents. The priority for applying the principle of shunts to electric regulators has been claimed simultaneously by Lontin, Tchikoleff, and Werner Siemens (or rather Hefner Alteneck, Messrs. Siemens' electrical engineer).

Lacassagne and Thiers' Regulator.—To set these claims at rest, we have to say that in Lacassagne and Thiers'

regulator with an overflow of mercury, patented in 1855, a shunting bobbin is offered, whose function it was to shorten the voltaic arc when the carbons were too far apart, by an overflow of mercury which, by raising the lower carbon-holder, shortened the arc. In this apparatus we even find, besides the principle of shunts, the principle of differential action as in Tchikoleff's and Siemens' apparatus; but in reality it has never acted as a division apparatus.

Tchikoleff's Lamp.—To remedy the drawbacks which have been mentioned with regard to electric regulators mounted for tension in the same circuit, Tchikoleff proposed, as early as 1869, to apply to the regulators the differential action of shunted currents.

Tchikoleff's first apparatus was a Foucault's regulator, in which the opposing spring was replaced by an electro-magnet, which received only a very feeble shunted current on account of the great electrical resistance of the fine wire of which it was formed.

The armatures of the two electro-magnets were placed at the two extremities of a rocker, carrying a lever for the release of the mechanisms used for the approach or withdrawal of the carbons.

The apparatus was in a state of equilibrium when the resistance of the arc was normal.

If the arc was lengthened, its resistance increased, the action of the fine wire coil preponderated, and, by causing a rocking motion of the armature, set free the mechanism for the approach of the carbons. The inverse effect, on the other hand, set free the mechanism for the withdrawal. Another model consists of a Gramme's ring placed between two diametrically opposed electro-magnets; one of these

with coarse wire, is traversed by the direct current, and the other, with very fine wire, by a shunted current; the ring can turn in either sense, according to the predominating influence of either of the electro-magnets. This double movement of rotation can be utilized to produce the withdrawal or the approach of the carbons, with this advantage, that the movements are the more rapid the further the apparatus is from its position of equilibrium.

The *Lumière Électrique* of the 1st of May, 1880, has reproduced two of these lamps, some of which have been used by the Russian artillery since 1877.

Tchikoleff's apparatus are arranged for continuous currents. They possess the advantage of acting without any clockwork, springs, or electric contacts; no previous adjustment is required either before or during the time of action, and the light remains constant in spite of any possible variations of the intensity of the current.

Lontin's Regulator.—This apparatus does not utilize the differential action of the current, but its action on an electro-magnet with fine wire, mounted in a shunt on the voltaic arc. Unlike Serrin's regulator, the pallet of the electro-magnet is arranged in such a manner that the lamp is always clamped, and the release is only produced when the arc attains too great a length; for then the current, passing into the shunt, becomes more intense, attracts its armature, and releases the mechanism for the approach of the carbons. In other models, the electro-magnet is replaced by a solenoid, which does not affect the principle, but prevents the vibrations of the armature when alternating currents are used.

With Lontin's apparatus, as many as twelve regulators have been placed in tension on one single circuit. With

one single Lontin's division machine, as many as thirty-one Lontin's regulators have been fed and arranged in different circuits by means of the manipulator, described on p. 92.

Mersanne's Regulator.—This regulator has been constructed with the view of obtaining a light for at least sixteen hours, by using very long carbons; only part of this length however is actually in the circuit, so as not to increase the resistance.

A clockwork is used for the movement of the carbons.

When the arc has a tendency to lengthen itself, a larger part of the current passes into an electro-magnet placed in a shunt; the armature sets free the clockwork, which causes an approach of the carbons until the resistance of the arc has gone back to its normal value.

The necessary retrogressive movement for the formation of the arc is obtained by a second electro-magnet established in the same circuit of the shunt, which only acts when the whole current passes into this shunt, either by the breaking of the arc or because the arc is not formed. At the moment when the current is sent into the apparatus, the whole current passes into the electro-magnets arranged on the shunts; the first sets free the mechanism for the advance, the second attracts its armature and pushes forward one of the carbons.

When the two carbons are in contact, the electro-magnets of the shunt become almost inactive, as the greater part of the current passes through the arc, and they release their armatures; the armature of the first electro-magnet arrests the advance of the carbons, that of the second produces withdrawal by the action of an opposing spring.

Siemens' Differential Lamp.—This apparatus, constructed by Hefner Alteneck, enables the inventor to place as many as ten lamps in tension on the circuit of a Siemens' alternating-current machine, at the same time rendering the action of each lamp independent of all the others.

This apparatus, too, is an application of the law of shunted currents, and of the differential action which they exercise in proportion to their relative intensities upon two circuits. Although the current is in reality alternating, we may consider it as continuous at a given moment, in order to understand the working of the apparatus. The current, arriving from the machine at L (Fig. 63), is divided into two parts: one part of the current traverses a coil T formed of very fine wire and of great resistance, and leaves by *b* L′ to enter the following lamp; a second part of the current traverses a coil R, with a coarse and short wire,—on leaving R, it traverses the voltaic arc formed between the carbons *g h*, and passes from *b* L′ over into the following lamp.

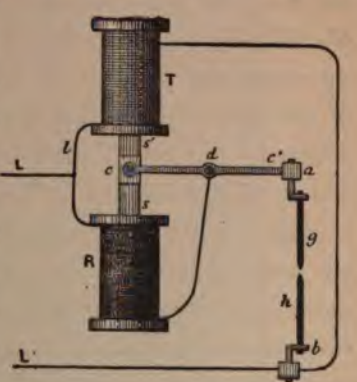


Fig. 63.—Diagram of Siemens' differential lamp.

The current is thus divided into two very unequal fractions: the weakest traverses the coil T, which has a fixed and very large resistance; the greatest part of the current traverses the voltaic arc, which constitutes a variable resistance with the withdrawal of the carbons. Let us place in the interior of each coil a soft-iron rod *s s′*, con-

nected by a lever $c\ d\ a$ with the carbon $g\ a$; and let us see what will happen.

Each of the coils attracts its corresponding solenoid with a force proportionate to the intensity and to the number of turns. It is clear, therefore, that for a convenient resistance of the voltaic arc, the relative resistances of the two circuits will tend to equalize the actions of the coils on the rods $s\ s'$, and the lever $c\ d\ a$ will take up a certain position of equilibrium. If the resistance of the arc increases, this equilibrium will be destroyed, the action of the coil T will become predominant, the lever $c\ d\ a$ will oscillate round d, and will cause an approach of the carbons. The opposite effect will be produced if the resistance diminishes, for then the coil R will act more energetically on the rod a', and a withdrawal of the carbons will ensue. The regulator no longer acts by the variations of the intensity of the current in the circuit, as in Serrin's lamp, but by the variations of resistance of the voltaic arc.

Such is the principle of the apparatus represented in its working condition in Fig. 64. If the action of the coil T preponderates, a small ratchet-wheel is released, which allows the upper carbon to descend by its own weight. In order to render that descent slow and regular, there is a sort of small pendulum, which only allows the escapement of one single tooth by oscillation, and as the descent can be arrested at each fifth part of an oscillation of the pendulum, the movements are absolutely imperceptible, and do not interfere in the slightest degree with the steadiness of the light.

The solenoid is connected with a little air-pump, in order to render its movements more gentle, and to prevent

it from vibrating under the influence of the alternate currents. When the withdrawal of the carbons is produced, the mechanism is raised, together with the upper carbon,

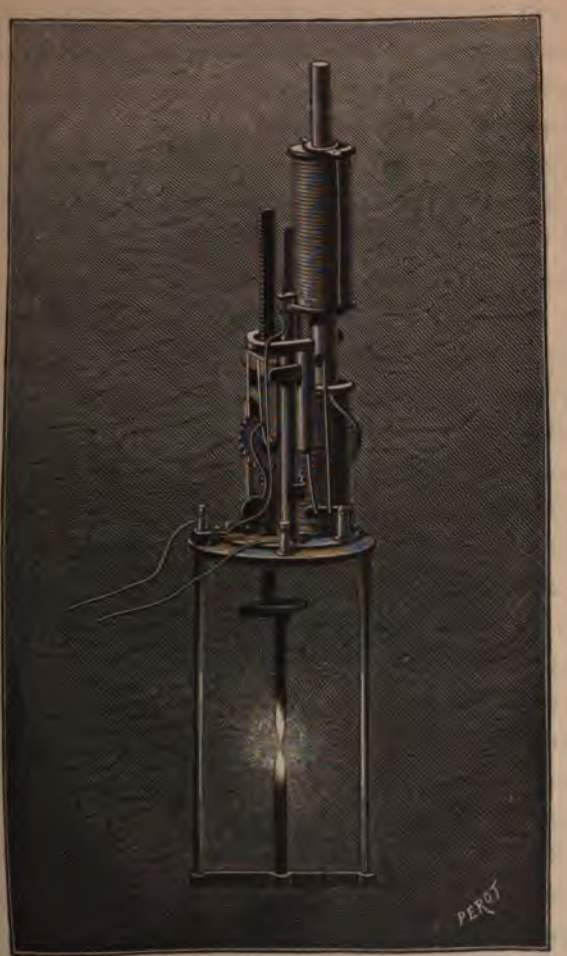


Fig. 64.—Siemens' differential lamp.

until the distance is reached for which the apparatus has been regulated. This regulation is very easily effected,

without an opposing spring, by raising more or less the coil of fine wire, in order to vary its action.

The lower carbon being fixed, the luminous point descends in proportion to the waste of the carbons, but as the mechanism is placed altogether above the luminous point, no shade is thrown by the socket of the apparatus, and this displacement entails no inconvenience under these conditions, especially when the lamp is placed rather high; the mechanism is hidden in a copper cylinder, which preserves it and is used for its suspension.

One of the lamps can be extinguished without interfering with any other; a key has only to be introduced into the communicator, which establishes a direct communication; on taking out the key, the extinguished lamp is immediately relighted.

Finally, a simple and ingenious contrivance must be mentioned.

The rackwork of the movable carbon-holder carries a small cross-beam; when the rackwork is at the end of its course, this cross-beam presses against two small platinum contacts connected with the terminals, and establishes a direct communication. This prevents the extinction of all the lamps of one circuit when the carbons of one of these lamps are used up, and it has been forgotten to replace them in time. A generator with sixteen bobbins expends, with its charging machine, about ten horse-power, and feeds twenty lamps of a power of about twenty-five Carcel burners (400 candles) each.

Brush's Lamp.—Like Siemens' lamp, this regulator is constructed on the principle of differential action, only, instead of employing two separate coils, Brush uses a solenoid with two wires—one short and coarse, placed in the same circuit

as the voltaic arc; the other long and fine, placed in a shunt on the arc itself. The upper carbon descends by its own weight, until it forms contact with the lower carbon, which is fixed.[1]

Gérard's Regulator.—The regulator is placed above the carbon, and is worked by alternating currents. It consists of a hollow electro-magnet (Fig. 65), allowing a free passage for the upper carbon. This electro-magnet, with a fine wire, is mounted in a shunt on the terminals of the lamp. An articulated brake, with a screw, keeps the upper carbon in position; the pressure of the brake against the carbon being regulated by a spring. The upper part of the brake carries an armature, and when this armature is attracted, the brake frees the carbon and allows it to descend.

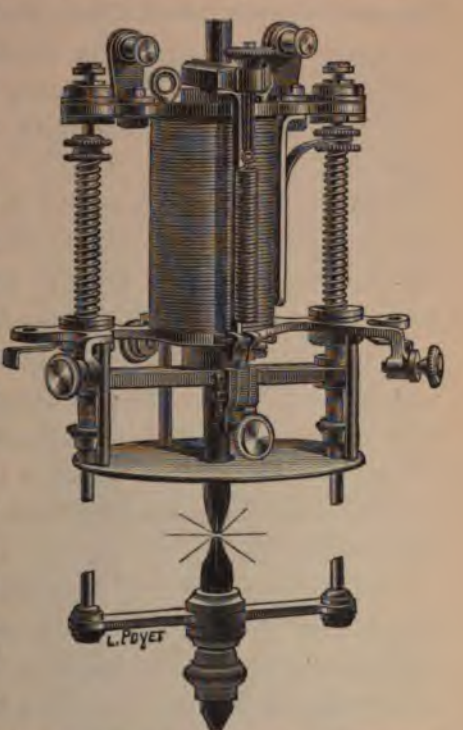


Fig. 65.—Anatole Gérard's shunt regulator.

The lower carbon is supported by a movable vertical frame carrying an armature at its upper end, and this

[1] A detailed description of these lamps and of the Brush system will be found on pp. 270, 279.

armature is placed at the lower extremity of the electro-magnet. The movable frame is balanced by two spiral springs, which are seen on the right and left of the electro-magnet. When at rest the carbons are not in contact.

The apparatus is worked in the following way:—When the current passes into the lamp, the carbons are apart from one another; the current can therefore only pass through the fine wire. The electro-magnet, consequently, becomes very powerful, and attracts both the upper and lower armature.

The upper armature, acting on the brake, frees the upper carbon and allows it to descend. The lower armature raises the frame and the lower carbon. As soon as the two carbons are in contact, the arc is formed, and the current which passes into the shunt is sensibly weakened. The lower armature is released, causes the lower carbon to descend, and thus produces the requisite distance. On the other hand, the lower armature of the brake is partly released, and the screw presses against the upper carbon and prevents it from descending.

If the spring is properly adjusted, balance is established; but in proportion as the carbons are wasted, the arc will be lengthened, and the intensity of the current in the electro-magnet will increase. The brake is now gradually loosened, the alternating currents will produce an oscillation of the armature, and the upper carbon slides down imperceptibly and continuously to maintain the requisite distance.

Gérard's Automatic Controller.—This apparatus instantly and automatically re-establishes the general circuit, and prevents the extinction of all the other lamps of the same circuit, when, from some reason or other, either accidentally

or purposely, a lamp ceases to act. It consists of a small wooden block, to which an electro-magnet with fine wire is fixed; this electro-magnet is connected to the upper terminals, which themselves are connected to the lamp; it is therefore mounted in a shunt. The two lower terminals (Fig. 66) communicate with two beakers half full of mercury; the left-hand terminal is connected to the arrival wire, and the right-hand terminal to the return wire of the current.

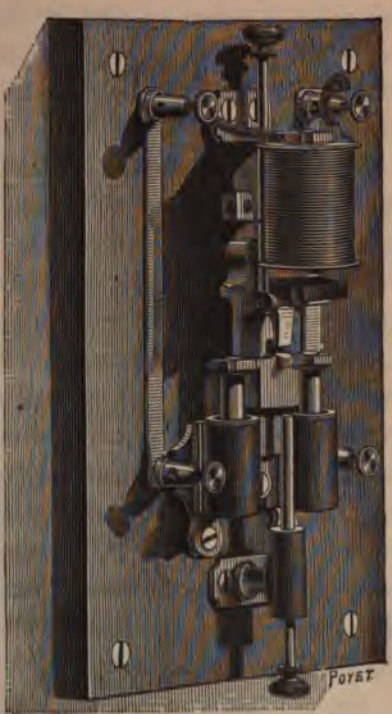


Fig. 66.—Anatole Gérard's automatic controller.

Underneath the straight electro-magnet is an armature carrying a small hook, to which, by means of a second hook, a cross-bar is suspended; this latter supports two iron rods placed immediately above the beakers with mercury. When the current passes into the lamp, the electro-magnet, which is mounted in the shunt, does not receive sufficient current power to attract its armature. When the current—as, for instance, in the case of an accident—no longer traverses the lamp, the electro-magnet becomes powerful enough to attract its armature, frees the hooks, and causes the iron rods to fall

into the beakers with mercury; a direct communication is established, and the lamp is short-circuited without interfering with the general circuit.[1]

This apparatus, as simple as it is ingenious, works in the most perfect manner. The two beakers can be placed one above the other; the principle remains the same, but less room is taken up, and the apparatus can be placed on the narrow pillars of workshops and factories, for which Gérard's lamp and his automatic controller seem to be specially adapted.

Brockie's Lamp.—This lamp is also a division regulator, in which the distance of the carbons is readjusted every minute or every half-minute, by automatically interrupting the circuit during a small fraction of a second. At the moment of interruption, the electro-magnet which maintained the carbons in position becomes inert, the upper carbon falls back into contact, and when a new current passes, the electro-magnet removes the carbons to their normal distance, and maintains them in that position until the next readjustment takes place. The eclipse is of so short a duration that it is almost imperceptible, and the waste of the carbons between two successive readjustments is so slight, that it does not sensibly affect the resistance of the circuit or the intensity of the passing current.

In the latest model, the readjusting electro-magnet is not placed in the circuit itself, but supplied by an auxiliary shunted circuit, and this circuit alone is affected by the interruptions of the current.

The Pilsen Lamp.—This lamp, invented by Piette and

[1] Strictly speaking, the lamp is not altogether withdrawn from the circuit, but in consequence of a direct communication being established between the two lower terminals by the beakers containing the mercury, the lamp only receives a current which is practically *null*.

Krizik, deserves attention especially because in it the two magnetic attractions arising from the same source regulate the light without any further mechanism, and without application of any other forces than those due to the current itself.

An extreme simplicity of construction has been obtained by this method, and the mechanical resistance and other deleterious obstacles have been reduced to a minimum. This result has been obtained in the following manner :—

The current, before entering the lamp, is divided into two parts, each of which traverses one of two superposed solenoids, in which an iron rod of peculiar shape slides up and down. The principal current traverses the first solenoid constructed of coarse wire, whilst the shunted current traverses a solenoid composed of a large number of very fine wire spirals. The relation between the resistance in the solenoid and the number of spirals has been calculated in such a manner that, as soon as the arc attains a fixed and determined resistance, the iron rod remains in equilibrium under the influence of the two solenoids. When the resistance increases, the equilibrium is broken and an adjustment takes place. The carbon could therefore be fixed directly to the rod, if the attraction of the solenoids for each position of the rod remained the same. But this is not the case. When an iron rod penetrates into a solenoid traversed by a current, the attraction is maximum when the end of the rod is at the same level as the medium line, of the solenoid. When the rod advances beyond that line, the attraction gradually decreases, and is equal to zero when the middle of the rod coincides with the middle of the solenoid.

This is the reason why a lamp constructed on the above

principle would not act well, for the adjustment could only be effected for very short distances.

Piette and Krizik have overcome this obstacle by giving to the rod a peculiar elongated form represented in Fig. 67 A, B, C, D.

Under these conditions, the attractive power of the solenoid remains the same almost for one-half of the rod,

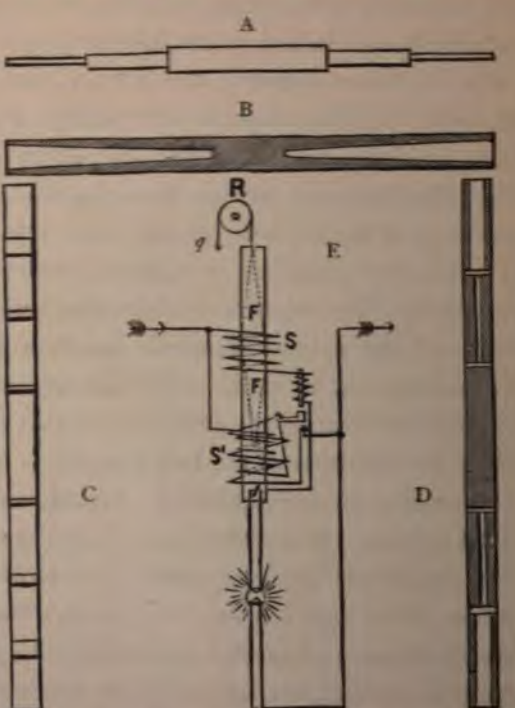


Fig. 67.—A, B, C, D, iron rods of Piette and Krizik's lamp; E, section of Piette and Krizik's differential lamp.

for different diameters of this rod correspond to differences in the attractive power of the solenoid.

A regular motion of the rod in the solenoid, for a considerable distance, can be obtained in this way, and the

carbon can be fixed directly to the rod without the intervention of an intermediate mechanism.

Fig. 67 E shows a section of the mechanism of the lamp, and Fig. 68 a view of the whole lamp as it was exhibited at the Paris Electrical Exhibition.

F F is an iron rod enclosed in a cylindrical copper box sliding on two rollers. Rod F F is suspended to a pulley R and balanced by a counterpoise *q*. The positive carbon, as will be seen from the figure, is fixed directly to the rod. The path of the current is the following:—The current arrives in the solenoid S through the conducting wire, passes through the positive carbon, the voltaic arc, and the negative carbon. The shunted current traverses the lower solenoid S^1, and returns to the circuit outside the lamp.

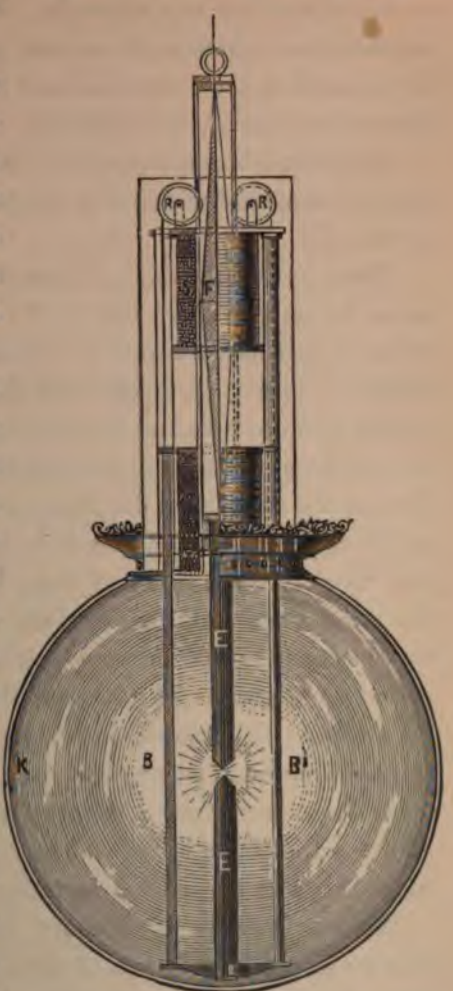


Fig. 68.—The Pilsen lamp.

For a given resistance of the arc, the rod is kept in equilibrium by the two solenoids. A waste of the carbons increases the resistance of the arc; the magnetic action of the solenoid in the shunted circuit increases, and the positive carbon descends with the rod.

The solenoids are superposed in such a way that the distance between their centres is equal to half the length of the rod.

The action of the solenoid placed in the principal circuit keeps the carbons apart, that of the solenoid in the shunted circuit brings them together. When, from some cause or other, the current is interrupted, the carbons remain at a certain distance from one another, for they are balanced by the weight q. If after this a current passes, it only passes through the solenoid in the shunted circuit, and the carbons are brought into contact only to be instantly removed again to a fixed distance. But if many lamps have to be lit in the same circuit, and the carbons are not in contact, the current can only pass through the shunts, and the resistance becomes too great. In this case the lamps cannot be lit. To obviate this inconvenience, each lamp has its own automatic commutator, which, before the carbons actually touch, sends the current into a spiral of coarse wire having a coil of fine wire at the lower end, and as soon as the carbons touch this wire is excluded from the circuit.

Various Regulators.—We are obliged to omit a great number of regulators, some of them very ingenious in principle, but which either practice has not sanctioned, or which have not had time yet to be practically tried.

Wallace and Farmer have constructed an apparatus with flat electrodes, working a long time without renewal of carbons, but presenting the same drawbacks as the

regulators with circular discs, which are now very rarely used.

Moléra and Cébrian have constructed regulators worked by hydraulic pressure.

Others, like De Fonvielle and J. Van Malderen, utilize the reciprocal repulsion of the electrodes under the action of the passing current; but in this case the apparatus is too delicate, and is affected by the slightest motion, because, the repulsion being very feeble, the equilibrium is most unstable.

There are few inventions on which so much ingenuity has been expended as on electric regulators; but here, as elsewhere, many are called and few are chosen. Our space has been devoted to the selected few, and also to some extent to the eligible ones.

CHAPTER II.

ELECTRIC CANDLES.

An apparatus with a voltaic arc in which the carbons are placed parallel and not end to end, is called an electric candle.

In 1846, William Edwards Staite invented an apparatus in which the carbons were placed in an oblique position (an intermediate apparatus between the regulator and the candle). In 1874, Werdermann patented a sort of electric candle for piercing the rock in mining and tunnelling operations, but which was not intended to produce electric light.

But the genuine electric candle which, by a complete absence of any mechanism and its extreme simplicity, has gained such notorious success, is due to a Russian officer, Jablochkoff, and dates from 1876.

Jablochkoff Candle.—The following is an extract from the patent, which accurately describes this invention:—

"My invention consists in the entire suppression of all mechanism commonly used in electric lamps. Instead of effecting by mechanical contrivances the automatic approach of the carbons in proportion to their combustion, I place these carbons alongside one another, separating them by an insulating substance which is capable of being consumed at the same time as the said carbons—kaolin, for

instance. The two carbons thus prepared can be placed in a special candlestick, and as soon as an electric current from some source or other passes through them, an electric arc is produced between the two extremities. For the

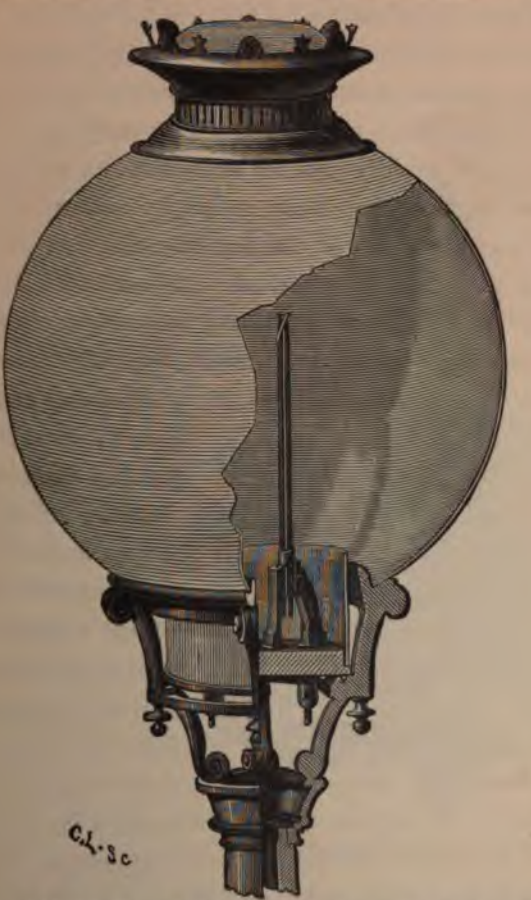


Fig. 69.—Jablochkoff candle (globes in the Avenue de l'Opéra, Paris).

purposes of lighting, I join the two free extremities by a small band of carbon, which first becomes red hot, and serves as a prime of the voltaic arc."

The candles, therefore, burn side by side, and are used up in the same time, like the wick of a composite candle.

The insulating matter maintains the arc at the extremity of the candle, and volatilizes in proportion to the combustion of the carbon.

It is a well-known fact that, in the voltaic arc, the positive carbon burns twice as quickly as the negative one. Jablochkoff has attempted to remedy this drawback, which would rapidly produce extinction on account of the unequal length of the carbon points, by making the positive carbon twice the size of the negative one; but practice has not yet sanctioned this method. At present all Jablochkoff candles have their two carbons, and are exclusively fed by alternating-current machines. Fig. 69 represents the Jablochkoff candle in its present form; the two parallel carbons have a diameter of four millimetres, and are twenty-two centimetres long, which ensures for the candles an average duration of one hour and a half. The lower ends of the carbons fit into two small brass tubes of five centimetres in length, separated by an insulating substance. In the Avenue de l'Opéra, four of these candles are placed in a globe, represented in Fig. 69, which softens the light, and makes it appear like a large luminous mass without any precise point of departure.

Fig. 70.—Lamp with four candles.

At the front entrance of the French Opera, the globes are of frosted glass, which is less diffusive, but absorbs less light.

The four candles are placed at the four corners of a square, in pincers with springs B C (Fig. 70), whose insulated branches are connected with the electric conductors.

A commutator, placed within reach of the hand, and enclosed in a box to screen it from any meddling on the part of the public, turns the current from a nearly wasted candle into a new one. When the globe contains four candles, five conductors are sufficient; the first four are each connected with a candle, and the fifth forms the common return wire.

A rapid movement of the commutator turns the light from one candle to another, and this momentary interruption of the circuit has no appreciable effect upon the light of the other candles in the same circuit.

The two carbons being insulated, it is indispensable, for the purpose of lighting them, that there should be a previous communication for a few moments of the two points of the candle. At first, Jablochkoff lit his candle directly by placing between the two extremities a piece of charcoal, which he removed afterwards when the arc was formed. In order to be able to light from a distance, Jablochkoff has placed between the two carbons a piece of graphite, fastened by a small ribbon or paper, which establishes a complete conducting circuit.

When the current is sent into the candle, the little piece of graphite is heated, becomes red hot, and is consumed. The voltaic arc then appears, and is maintained as long as the candle lasts and the electric current is sufficiently powerful. The graphite can be replaced by a fine metallic wire or a piece of lead.

At the Hippodrome, in Paris, Geoffroy effects the priming by means of a paste of special composition, with carbon as chief ingredient, which produces the same effect. By this means, half-burned candles can be used again by priming them afresh.

Gadot has used different substances for the insulating matter, to give it a certain conductivity, sufficient to allow the current to pass into all the candles at the same time. A larger quantity of the current passes into that candle which, from some difference in the mode of its manufacture, has the least resistance, and heats it; its conductivity is thereby increased to such an extent that light is produced. If the candle breaks, or burns to the end, it is extinguished, and the current lights that one of the remaining candles which possesses the least resistance, and so on. The drawback to this system is that it creates in the candle shunted currents causing an appreciable loss of electricity. The increase of conductivity of the insulating matter produced by heat is so large, that the circuit of a brightly burning candle can be interrupted for nearly two seconds without leading to its extinction or that of any other candle in the same circuit. After a certain time, the cooling destroys the conductivity, and the lighting becomes impossible from a distance; the candle must be primed anew.

The Jablochkoff candle has found a great number of applications, some of which are described in Chapter IV. Direct measurements of the work expended and the illuminating power obtained have repeatedly been made.

We quote some of the results of these experiments from a report presented in May, 1879, to the Metropolitan Board of Works, by Messrs. Bazalgette and Keates.

The first installation, which was made on the Victoria

Embankment, consisted of twenty candles fed by a Gramme's machine with alternating currents, arranged in four circuits of five candles each.

The work expended by the machine was, deducting the work expended by transmission and by the machine working in open circuit—

				Total work gross.		Work net.	
For 5 candles, or 1 circuit utilized,				13·57	horse-power, or	1·57	per candle.
10	„	2	„	17·91	„	1·27	„
15	„	3	„	20·75	„	1·05	„
20	„	4	„	23·53	„	0·92	„

The illuminating power has been found to be—

For one candle with open light.....		39·8	Carcel burners, or	640	sperm candles.
„	„ frosted globes .	27·9	„	450	„
„	„ opaque globes	16·3	„	256	„

Opaque globes thus cause a loss of nearly sixty per cent. of the light emitted, and frosted globes nearly thirty per cent.

Of all the systems of electric lighting the Jablochkoff candle is the most extensively used; more than 2500 of these candles were in use in Paris twelve months ago, and there is no doubt that, with successive improvements and lowering of price, it will even find a greater development in the future.

The only drawbacks to the Jablochkoff candle are its incessant variations of tint and brilliancy, and the impossibility of effecting an automatic relighting. The former of these defects may be lessened by improvements in the construction of the candle and the manufacture of the carbons, but it is extremely doubtful whether it will ever disappear completely.

As regards a self-acting mechanism for relighting, Makaire

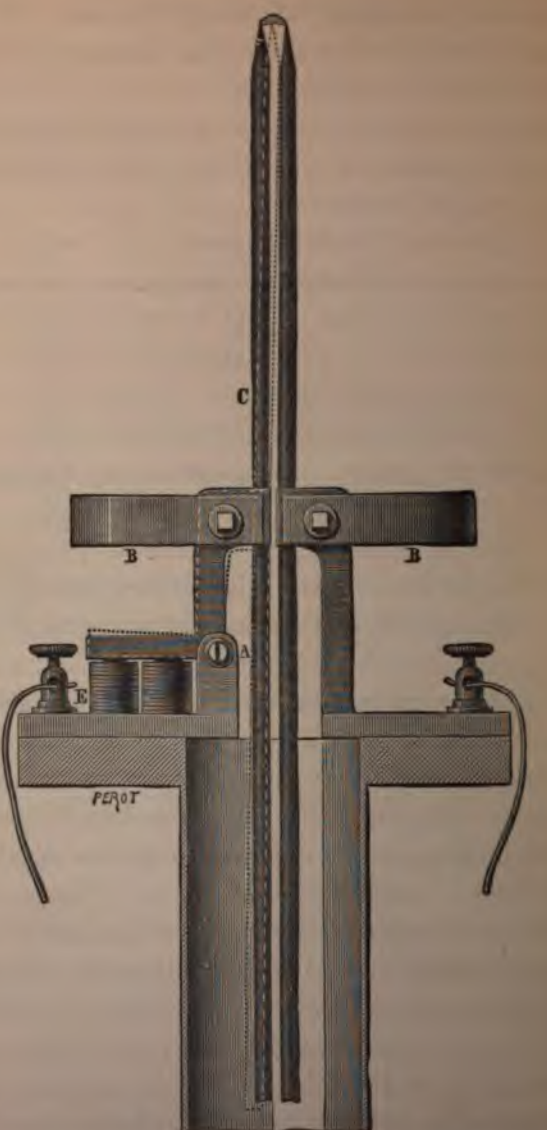


Fig. 71.—Wilde's candle (half natural size). C, movable carbon; A axis of rotation of the support of the movable carbon; B, springs of th rollers; E, electro-magnet.

has already constructed a very ingenious apparatus for this purpose, which, with some slight modifications, will become practical.

Wilde's Candle.—We have seen that in the Jablochkoff candle an insulating substance is used placed between the two carbons of which it is formed. In the candles we are going to describe, and which have hitherto found only a small number of practical applications, the insulating matter is entirely absent.

Wilde's candle (Fig. 71) consists of two parallel carbons of four millimetres diameter, placed at a distance of about 3·5 millimetres from one another. Each carbon is fixed to its support by means of a flat, U-shaped steel spring B (Fig. 72), to whose extremity is fixed a roller D, which

Fig. 72.—Pincer with rollers of Wilde's candle. M, fixed supports; D, copper rollers; B, springs.

keeps the carbon in position by pressing it against the support M, allowing it at the same time to slide upwards. The carbon on the right is fixed; the support of the left carbon is articulated in A. If the current does not traverse the apparatus, the left carbon takes up the position marked by dotted lines; the circuit is then closed by the electro-magnet E, the two carbons, and the terminal fixed to the right hand support. But now the electro-magnet becomes active; it again attracts its armature which had gone to join the rocking carbon support C, and the carbons

are placed in a parallel position. This simple arrangement completely realizes the conditions of a self-acting apparatus.

If, from some reason or other, the candle goes out, the electro-magnet becomes inactive; the carbon C again takes up its inclined position, and produces automatic relighting, if the circuit is complete in all the other parts of the system. Wilde's candle burns, therefore, like a Jablochkoff candle without an insulating substance, at the rate of ten to twelve centimetres per hour, with an illuminating power varying from thirty to eighty Carcel burners (480 to 1280 sperm candles), according to the power of the passing current.

Carbons of sixty-five centimetres length represent about five hours' lighting; the luminous point is, at the moment of lighting new carbons, at a distance of about twenty centimetres from the supports.

At the end of about an hour and a half, the arc has sunk down to C by the waste of the carbons; these are now pushed upwards by raising a small disc inside the tube with the help of a screw fixed on its side; the carbons slide upwards in their support, by the intervention of the rollers D (Fig. 72), and the candle is lengthened by a fresh amount. This operation is effected very rapidly, without extinguishing the candle, and resembles the raising of a candle in a common candlestick.

For long periods of lighting, Wilde places on a socket a series of candles in the form of a crown, the size of the candles being calculated to give from one and a half to two hours' light. By turning this socket either by the hand or by a self-acting apparatus, the candles are successively placed in the circuit. The luminous point is thus always placed in the centre of the diffusing globe, and the shade of

the unconsumed candles is projected on the side where it interferes least with the light.

The candle can be turned upside down, and burns as well as in its natural position; the waste of the carbons is slightly increased in this second position. If the arc is extinguished, Wilde's system produces automatic relighting; the extinction does not last for any appreciable length of time. Wilde's candle and machines are the property of the Alliance Company, which proposes to push the application of these apparatus in Paris.

Rapieff's Candle.—Rapieff's apparatus was invented about the same time as Wilde's, which it resembles in all its essential parts. We mention it here in its historical order, without entering upon the question of disputed priority of which we find many instances in the history of electricity.

Jamin's Candle.—In this candle, which was invented by Jamin, in 1879, and whose first model is shown in Fig. 73, the two parallel carbons are placed in the candlestick; they are surrounded by a wire in which parallel alternating currents circulate which feed the candle. To light the candle, a piece of charcoal, used for the priming, is placed between the extremities of the two carbons. If the priming is effected midway between the carbons, the voltaic arc produced at this point is rapidly carried to the extremity of the carbons, where it remains, whatever the position of the candle. The whole novelty of Jamin's invention consists simply of this removal of the arc, which is brought about by the directing action of the currents surrounding the apparatus.

The current circulates in the parallel carbons and the wires surrounding them in such a manner that, at a given moment, it ascends through the right hand carbon and

descends through the carbon on the left; it ascends equally through the wires on the right and redescends through those on the left. The voltaic arc, which is nothing but an element of the current, is displaced in the sense indicated by Ampère's law.

It is at the same time attracted upwards by that part of the current which passes above, through the attractive force of parallel currents of the same sense; and pushed upwards by that part of the current which passes beneath, through the repulsive force of parallel currents of contrary sense; it is likewise pushed upwards by the tendency of the right hand current to turn the movable current in a parallel sense; and finally pushed in the same direction by the same tendency of the left hand current.

The four actions are concurring, exactly as in a galvanometer the four parts of the wire (two vertical and two horizontal ones) concur to cause a deflection of the needle.

The energy of this action can be varied *ad libitum*. By increasing the number of coils which surround the apparatus, the energy in question increases in the same ratio. On the other hand, the directing action of an element of the surrounding current on the movable element—the voltaic arc—being proportional to the simple distance, a surrounding circle acts in the same way, whatever may be its diameter. (If it becomes too large, the action of each element decreases as the radius increases, but the number of these elements increases as the radius, and an accurate compensation is the result.)

It may happen that the action is too strong, the current being carried upwards with such violence that its course can hardly be followed with the eyes, and that, on arriving at the end of the carbons, it is still pushed further, is

lengthened, and breaks. The remedy in this case is simple: by diminishing the number of the surrounding coils, the forces are brought back to a stable equilibrium.

Jamin has constructed a second candle, where, by means

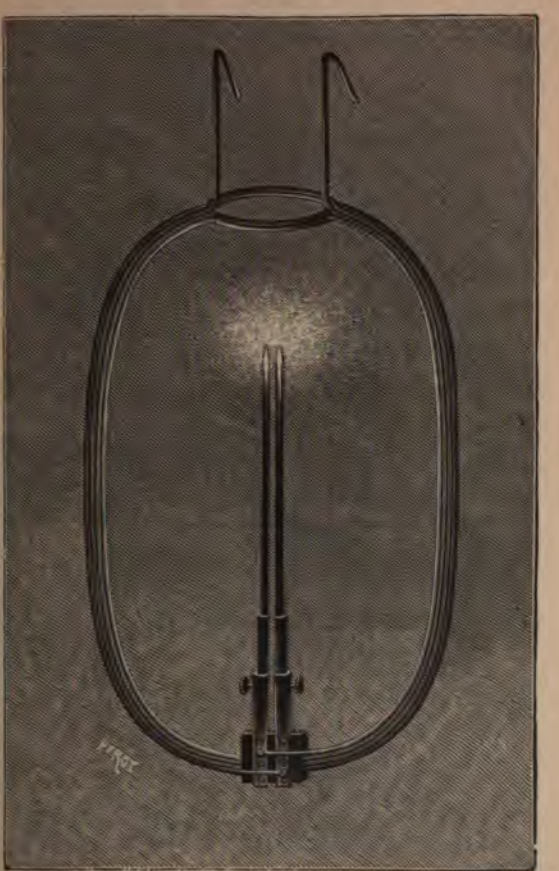


Fig. 73.—Jamin's candle (1879).

of magnetization of a contrary sense produced by alternating currents, an oscillating movement is communicated to the carbons, simultaneous with the passage of the currents.

When no current passes, the carbons are in contact, and are lit as soon as the circuit is closed.

This oscillating motion of the carbons leads, according to Jamin, to a more thorough utilization of the alternating current, which can only traverse the arc if its intensity is sufficient to overcome its resistance.

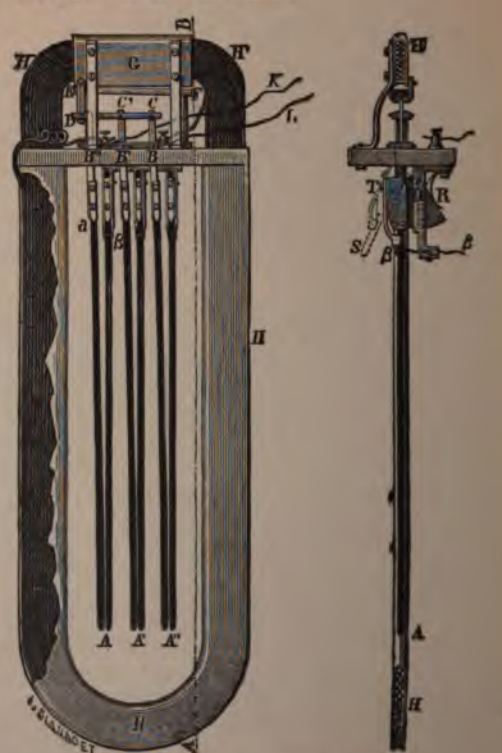


Fig. 74.—Jamin's candle (1880).

By an approach of the carbons when the intensity diminishes, the current is made to pass during a longe time at each oscillation, and the utilization is from this caus increased to a certain extent. The motion of the carbon causes a more rapid circulation of air, and thus facilitate

the combustion of the carbons. But supposing even this vibratory motion of the carbon possessing all the advantages attributed to it by Jamin, there is the drawback of a considerable noise, which renders the candle inconvenient in a room. All electric apparatus worked with alternating currents are subject to this inconvenience, and this constitutes an advantage in favour of continuous currents.

An experiment made on the 3rd of June, 1880, with a third model of a Jamin's candle, proved to be nothing else but an identical reproduction of the relighting of a Wilde's candle. The electro-magnet G (Fig. 74) causes the withdrawal of the carbons by attracting a small armature E F at the moment of the passage of the current; by a combination of levers E D, D C, this armature removes the left hand carbon of each candle A, A′, A″. The arc is at first developed on the three candles, and after a short delay is fixed to that candle which has the least resistance. When one of the candles is consumed, the arc burns a small brass hook B placed at the upper end; the carbon support, through the action of a spring R, then assumes the position O S, the arc is broken, the carbons fall down, and a new candle is lit. The carbons must, therefore, be most carefully prepared, and the adjustment most accurate, if the three candles are to act each in its turn, and burn to the end without any accident.

Jamin's candles thus possess all the drawbacks of a regulator, without its corresponding advantages, for it is impossible so to regulate the proper resistance of each apparatus that the current it receives should be regularly expended.

At the moment when the arc is lengthened, it consumes

more electrical energy at the expense of the other lamps; the reverse takes place when the arc is shortened. These changes in the resistance are also shown by differences in the intensity of the light. Wilde's candle has this drawback in common with Jamin's candle. In Jablochkoff's candle the kaolin keeps the carbons parallel, and partly compensates these defects; but the compensation is obtained at the expense of notable changes in the tint of the light.

In all electric candles, therefore, simplicity of construction can only be obtained at the expense of the quality of the light, its steadiness, or its tint.

To maintain the arc at the extremity of the carbons, Jamin always uses his guiding frame. This guiding frame H H, formed of forty coils (instead of six used in the first model), introduces a very appreciable resistance into the circuit, and thereby produces an unfavourable result, which to a great extent counteracts the advantage arising from the reversed position of the carbons. In short, Jamin's third apparatus is far from realizing all the advantages that were expected of it.

Debrun's Candle.—Debrun's candle, with a self-acting relighting arrangement, consists of two parallel Carré's carbon pencils of six millimetres diameter, and twenty to thirty centimetres long, two to three millimetres apart from one another, and maintained in their parallel position by a small glass plate placed at the foot between the two carbons. The whole is secured by insulating varnished paper and two bands of iron wire. For longer periods of lighting, two candles, instead of one, can be placed in a specially constructed lamp, and these two candles are lit successively and automatically.

At the foot of the candle is a small electro-magnet,

whose armature carries a small piece of carbon; when traversed by the current, the electro-magnet attracts the armature and presses the carbon against the foot of the candle. Contact is thus established, and the arc is formed at the foot of the candle. As soon as the current traverses the candle, a small electro-magnet, in the same circuit as the candle itself and set up apart as a relay, acts on an armature connected with a mercury commutator, and breaks the circuit of the electro-magnet which was placed in a shunt.

The current, therefore, traverses the candle alone, and is swiftly carried to the upper extremity by the current of hot air which is produced at the foot. As long as the candle burns, the electro-magnet of the relay keeps the lighting circuit open and the small piece of carbon away from the candle. If the candle is extinguished, the commutator of the relay is released, closes the circuit of the candle electro-magnet, and the same series of phenomena repeats itself.

When the first candle is consumed, the arc burns a small brass wire at the bottom, a spring of coarse brass wire is released, and conveys the current from candle No. 1 to candle No. 2, which is lit in the same way.

All electric candles possess two very serious drawbacks, which render them inferior to regulators: the first is the noise produced by the alternating currents which are obligatory for the uniform waste of the two carbons; the second results from the very position of these carbons and their fixed distance. The arc passes between the points, and a part of the light is thus eclipsed; from want of regulation in the distance of the carbons, this distance may, at a given moment, not be proportional to the intensity of

the current, hence the want of stability of the light of all these candles.

In order not to use them up too quickly, they are fed by currents of feeble intensity—eight or nine ampères for candles of four millimetres. In proportion as the regulators are improved and simplified, the electric candles lose their importance, always excepting the Jablochkoff candle, the extreme simplicity of which will never be equalled.

Sun Lamp.—This apparatus, invented by Clerc and Bineau, is intermediate between a Jablochkoff candle and an incandescent lamp. Although its form only vaguely reminds us of a candle, we mention it here so as not to have to assign to it a special class.

Figs. 75 and 76 show its construction. Two carbons C C, slightly deviating from the vertical position, are placed between a central piece B of white marble or condensed magnesia and an exterior piece of some stone or other; they descend by their own weight in proportion to the waste of their lower part, and are kept back by a small ledge or shoulder which is seen on the exterior stone. The whole of this arrangement is placed in a cast-iron box A A open at the bottom. This box is suspended by a large stirrup, to which the conducting wires are connected.

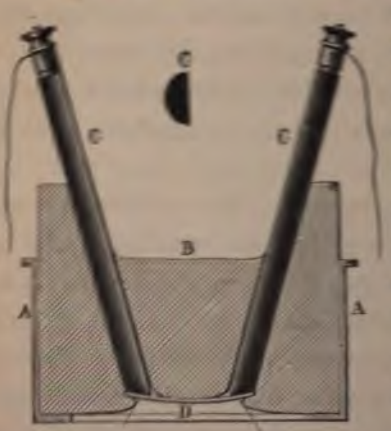


Fig. 75.—Diagram of the sun lamp.

The conducting wires convey the current to the upper

end of the two carbons. Before lighting, the carbons rest on a small and fine piece of carbon D, which is heated by the passing current, is rapidly consumed, and prepares the production of the voltaic arc, like the prime of the Jablochkoff candle.

When once the arc is established, it is maintained in spite of the great distance between the carbon ends, because the surface of the marble, or the magnesia between them, has had time to become a conductor, through being heated during the preparatory period of lighting.

This arc of great length heats the marble, and produces an intense light of yellow tint, to which it owes its name.

The sun lamp throws all its light downwards, which is as a rule desirable, but the total suppression of light in any other direction is sometimes objectionable. Moreover, the different pieces surrounding the luminous part of the marble throw a shade and assign to the luminous rays a limited area.

The light measured in a vertical direction, that is to say, in the direction of its maximum intensity, was in one particular case of 120 Carcel burners per lamp of one horse-power and a quarter, or about 100 burners, or 1600 sperm candles, for one horse-power.

In another series of experiments, it has been found that the efficiency varies from fifty Carcels per horse-power with an intensity of five ampères, to 110 and 125 with fifteen to twenty ampères. The luminous intensity, moreover, can vary from 50 to 1000 Carcels, according to the distance of the carbons, the length of the marble block, and the intensity of the current.

To stifle the noise of the alternating currents, the lamps must be hermetically closed.

The luminous point is absolutely fixed, and the light is perfectly steady—two very important advantages of this lamp. A further advantage is the very considerable time during which the lamp can act without stoppage, without

Fig. 76.—The sun lamp (perspective).

renewal of carbons, and without any personal attention. The waste of the carbons varies from eight to fifteen millimetres per hour, according to the intensity of the current, which can vary from three to twenty-five ampères. The

length of the carbons can vary from five to thirty centimetres, and the lamps can act for fifteen or sixteen consecutive hours, if necessary.

The marble block between the two carbons is likewise wasted; the very high temperature to which its lower part is exposed causes a decomposition of the calcic carbonate, quicklime is formed, which is rendered incandescent by the arc. A marble block can last for twenty consecutive hours, or for two lighting periods of ten hours; it does not last so long if the lighting periods are of two or three hours respectively.

The length of the arc can vary from ten to sixty millimetres, according to the resistance for which it is intended. For a short circuit, greater intensity and a thinner marble are required; for a long circuit, a higher tension, less intensity, and a thicker marble must be employed. The lamps commonly used in practice have a slab of marble or magnesia of ten to twenty millimetres thickness.

Latterly, condensed magnesia has been substituted for marble, because it lasts much longer; it is not decomposed by heat, and can last for 100 hours.

Various Electric Candles.—Soligniac has constructed candles with four carbons. The two on the outside have four millimetres diameter; the two in the centre, two millimetres and a half. The four carbons are placed in the same plane, at a distance of half a millimetre, without any intermediate insulating material. The current passes into the candles by the two exterior carbons, which are fastened to two copper sockets. These candles work very well, but are rather delicate in their construction and their manipulation. They are not used in practice.

Gadot proposed to use substances of inferior conductivity

for the preparation of the separating material, in order to obtain an automatic relighting by means of shunted currents. This system was used for the lighting of the French Salon (yearly exhibition of paintings), in 1879, and yielded a slight economy in the length of the cables. The lighting of the candles necessarily commenced with the one that had the least resistance. It has been given up on account of the losses due to shunted currents, which weaken the illuminating power to a very great extent.

The Abbé Lavaud de Lestrade has constructed a candle-bearer floating on mercury, with the object of maintaining the luminous point at the same height, by means of the waste of the candle and its diminution of weight.

CHAPTER III.

LIGHTING BY INCANDESCENCE.

In all apparatus which we have hitherto described, the light is produced by the voltaic arc, which implies a longer or shorter distance between the two conductors. This space is occupied by gas raised to a very high temperature, and by particles of carbon detached from the electrodes. In the systems about to be examined now, the light is produced by a solid body raised to a very high temperature by the passage of an electric current.

In electric lighting by incandescence, two large classes must be distinguished, founded on different principles.

1. *Incandescence with combustion;* systems, Reynier, Werdermann, etc. The light is produced by a carbon point which is traversed by the current and more or less quickly consumed. The heat given off by its combustion, added to that of the electric current, prevents the cooling of the incandescent carbon, and thereby increases its luminous power.

2. *Incandescence alone.* In these apparatus, the electric current passes through a substance of comparatively small conducting power, and heats it till it becomes luminous, but without destroying the substance itself. There is, in reality, no electric lamp which completely realizes these conditions; but under this category come all the apparatus

that have been constructed with this aim, although it may not have been completely attained.

For these apparatus, either carbon filaments or metals difficult of fusion, such as platinum, an alloy of platinum and iridium, or iridium by itself, are used.

Incandescent Lamps with Combustion.

The first incandescent lamp dates back as far as 1845, and is due to De Moleyns; but the principle of an incandescent lamp with combustion was patented as late as 1876, by Varley; and even his lamp is only an intermediate arrangement between real incandescent lamps and regulators with a voltaic arc. These apparatus are sometimes called lamps with imperfect contact.

Varley's Lamp.—The following is the description that Varley gives of his lamp in his patent of 1876:—"A carbon point T (Fig. 77) presses slightly by its weight and its mounting U against the periphery of a roller of gas carbon N; hence results imperfect contact, and, consequently, incandescence and combustion of the carbon point at its extremity."

Fig. 77.—Varley's lamp.

It seems, however, that the light was produced in this lamp by a series of sparks, which owed their formation to the composition of the roller N, which consisted of alternately conducting and insulating parts, as well as to its rapid rotatory motion.

Reynier's Lamp.—Émile Reynier constructed, in 1877, the first electric combustion lamp founded on the incan-

descence of a carbon point which was traversed by an electric current. Reynier was led to the construction of his lamp by making experiments on pure incandescence with some Russian lamps which will be mentioned hereafter. All these lamps had one and the same serious defect—the waste of the central part of the carbon, which brought about its rupture, and necessitated the substitution of a fresh carbon.

Reynier was led to believe that, if the extremity of the carbon point touched another massive carbon, the waste

Fig. 78.—Enlarged image of the carbon of an incandescent lamp (Reynier's system).

would be produced at the point of imperfect contact where the temperature was highest, on account of the electrical resistance due to this imperfect contact.

If the carbon was burned at its extremity, it only required pushing upwards, like the candle in a carriage lamp. The combustion of the carbon even increased the light, the heat produced by it being instrumental in keeping up a very high temperature.

The characteristic part of Reynier's apparatus is, therefore, a carbon point pressing against a fixed contact (Fig. 78), and rendered incandescent between this point of contact and another, situated at some distance from the first. The first lamp was worked with four Bunsen elements (Ruhmkorff's model), a Gramme's laboratory machine, and even with a secondary battery of three Planté elements.

In his first experiments, Reynier found that the fixed, immovable carbon against which the incandescent carbon pressed, did not answer its purpose. He therefore gave it the shape of a disc, which slowly turned round on its horizontal axis. *La Nature* of the 24th of August, 1878, represents two different models of Reynier's lamp, which was afterwards simplified by the inventor in the following manner:—

The carbon pencil is pushed downwards by its own weight and that of the carbon-holder, directed by guiding rollers; it comes to press against a carbon disc, which is somewhat in advance of the vertical line passing through the centre of the disc, and the descent of the pencil arising from its waste thus turns the disc without any mechanism. The carbon is maintained at a short distance by a cylinder; and another carbon contact, which determines the incandescent length, presses against it from beneath. By a very simple contrivance, the pressure exercised by the carbon on the disc is transmitted, and acts as a check on the motor carbon-holder. The weight of this latter is, therefore, effectually kept back as long as the carbon retains its original length and presses against the disc; and, on the other hand, is set free as soon as the lower support gives way through the waste of the carbon

pencil. It is worthy of note that the highest temperature is at the lower point of contact, and that the slow combustion in air lessens the size of the carbon towards its lower end, and thus facilitates its advance. Instead of being a drawback, as was the case in the old lamps, this accessory circumstance has been turned to profit in Reynier's system.

The lamp can be introduced into the circuit of a Gramme's machine supplying a regulator, and can thus furnish an additional light, without sensibly interfering with the principal light furnished by the voltaic arc.

Reynier's lamps present a certain elasticity as regards their illuminating power, for, according to the intensity of the traversing current, they can give a light varying from four to forty Carcel burners (64 to 640 candles).

Reynier's Lamp, Model of 1879.—In this latest form of Reynier's incandescent lamp, the carbon C (Fig. 79), pushed by some mechanism in the direction of the arrow, presses against the contact in B; the lateral contact L, mounted at the extremity of a lever, presses against the carbon by the action of a spring r, and confines the incandescence of the carbon point to the limits i and j.

The contact with the end-piece B is placed in a holder, fixed in the lower socket of the burner. To introduce the carbon into the lamp, this holder with the end-piece is taken out, the carbon is pushed into the open tube, and the holder put back into its place. The apparatus is now ready to act.

The incandescence, as we have mentioned, is limited to the space between i and j, and its length can vary from four to eight millimetres. The light obtained is from five to twenty-five Carcel burners (80 to 400 candles) for each apparatus, according to the intensity of the electric current and the length of incandescence determined upon. With a

battery of eight Bunsen elements (Ruhmkorff's model), a light equivalent to about twelve Carcel burners (200 sperm candles) is produced. If the apparatus is worked by magneto-electric machines, it can produce, per horse-power, from three to five light-giving centres of eight to fourteen burners each. This gives an illuminating power of thirty

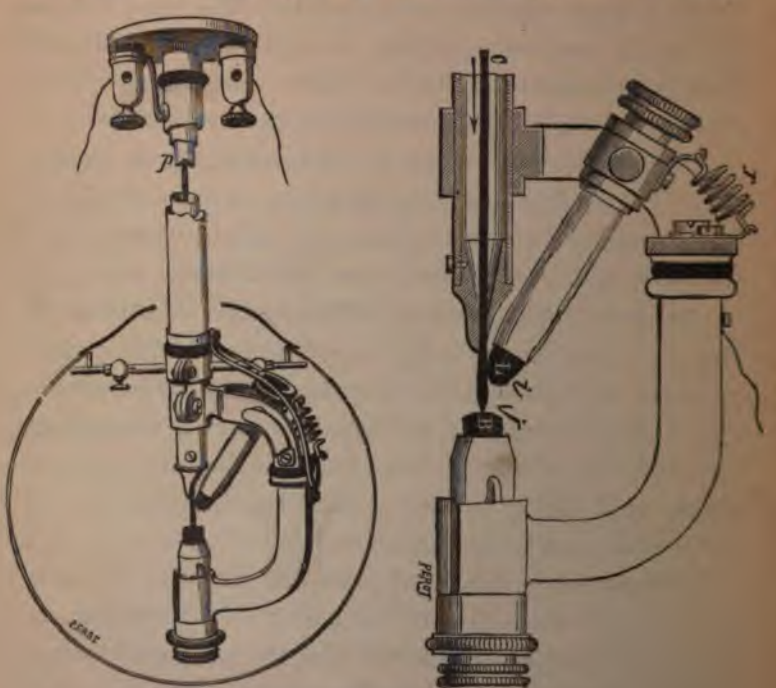


Fig. 79.—Reynier's lamp (1879).

to forty Carcel burners (about 500 to 600 sperm candles) per horse-power.

A given burner can easily be adapted for lamps of different forms. Reynier has constructed apparatus with a downward action, by means of a counterpoise or of hydraulic pressure; a lamp with a drum, acting in any position; and,

simplest of all, a suspended apparatus, which is represented in Fig. 79. Here the advance of the carbon is obtained by the descent of the cylinder *p*, which presses directly against the carbon.

Reynier's Self-acting Lighter.—If from eight to twelve lamps are placed in tension on an ordinary Gramme's machine, as in the applications of Reynier's incandescent lamp, the accidental extinction of one single lamp causes the extinction of all the others; and in the sudden darkness

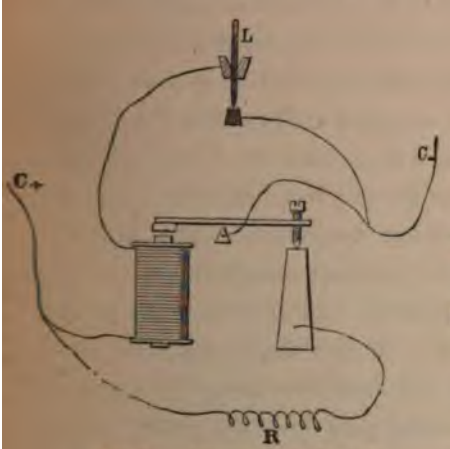


Fig. 80.—Diagram of Reynier's self-acting lighter.

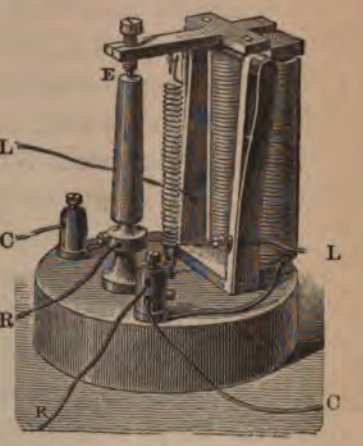


Fig. 81.—Practical form of Reynier's self-acting lighter.

it is impossible to find out which lamp is at fault. This, of course, is a very serious drawback, and accidents of that kind will be the more frequent the larger the number of light-giving centres.

To guard against this serious inconvenience of a partial extinction, Reynier employs a self-acting apparatus, called an *allumeur* (lighter), whose construction will easily be understood by a reference to Fig. 80.

The principal conductor C C, instead of being in direct

connection with the terminals of the lamp, is fixed to the lighter, where it is shunted into two circuits of equal resistance, namely, lamp L, and a spiral R of German silver. The shunted current, passing through the lamp, magnetizes an electro-magnet, whose function it is to break, by means of a lever, the shunted current in the wire R; this latter current is closed again automatically by the same lever when the electro-magnet is demagnetized.

Fig. 81 represents the lighter in its practical form. C C are the main wires; L L, the conductors connected with the lamp; R R, the connections of the shunted circuit. The following contingencies may arise in this system :—

1. The lamps being all supplied with carbon, the circuit is closed: the current is for a moment divided between the wires of the shunt and the lamps; but immediately afterwards the electro-magnets are magnetized, open all the shunted currents, and the lamps alone remain in the circuit.

2. At the moment of lighting, one or several lamps are without carbon: the lighters of the lamps supplied with carbon act in the way that has been described; the currents of the lamps without carbons pass into the shunt wires, and the carbons can be replaced without interfering with the intensity of the current or the illuminating power of the lighted lamps.

3. A lamp which has been acting, stops from want of carbon or some other accident: the lighter connected with the lamp closes the shunted circuit, and all the other lamps are not affected.

4. During the action of the other lamps, a lamp is supplied with carbon: the current is for a moment divided between this lamp and the resistance of its lighter, whose electro-magnet is immediately magnetized, opens the

shunted current of the resistance and short-circuits the lamp.

The lighter, as will be seen, fulfils all requirements. It renders the lamps practically independent from each other, and requires no personal attention.

Werdermann's Lamp.—Certain arrangements of Reynier's lamp are reproduced in this lamp, but the most characteristic point consists in the reversed position of the apparatus.

In Werdermann's first model, patented a few months after Reynier's system, the negative carbon, placed in the upper part, consists of a carbon disc of large diameter; the positive carbon is an ordinary carbon pencil of four and a half millimetres diameter.

A simple spring ensures a permanent contact of the carbon with the positive electrode; the carbon is pushed by a weight in proportion to its waste.

Does Werdermann's lamp produce a voltaic arc or no? This question, which is often asked, resolves itself simply into a matter of definition. If by the term "voltaic arc" is meant a material interval between the two electrodes, an interval filled with gaseous molecules and particles of carbon raised to a very high temperature, Werdermann's lamp does not produce a voltaic arc. The very fact of the carbon point being pushed upwards must necessarily bring about a contact between the disc and the point, although this contact can be rendered very slight by means of a check employed in the last model.

But in incandescent combustion lamps, the high temperature produced by the electric current strongly heats the atmosphere surrounding the luminous point, while particles of carbon, detached from the positive electrode, are consumed in it.

We find, therefore, in this part of the lamp a halo of very high temperature, of great conductive power, and full of particles of carbon—in short, all the necessary conditions for the formation of the voltaic arc properly speaking.

In Werdermann's first experiments, the lamps, ten in

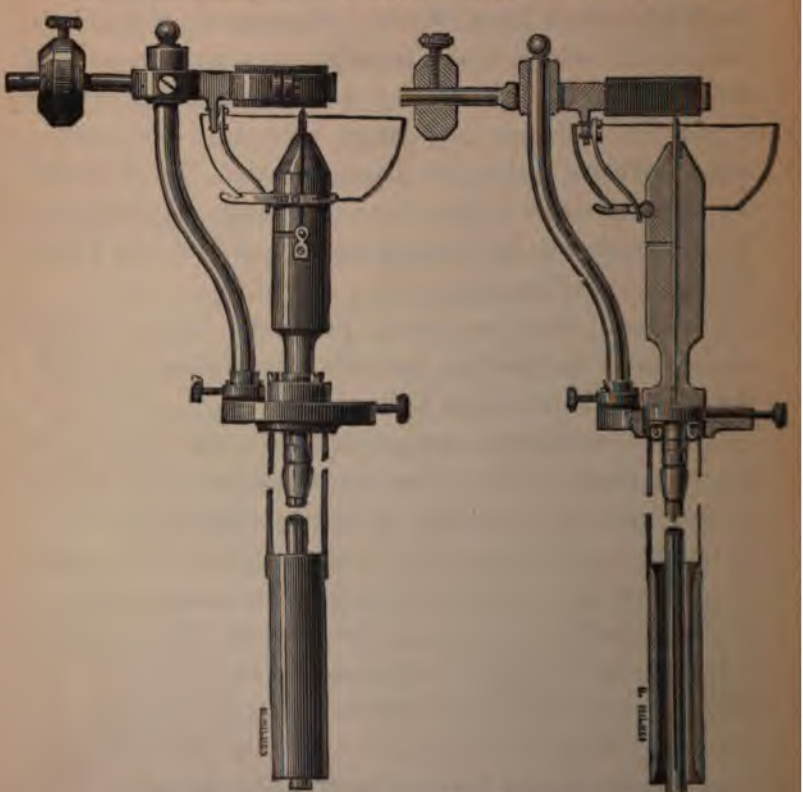


Fig. 82.—Werdermann's lamp (elevation and section).

number, were mounted in shunts on the same circuit. A Gramme's machine was sufficient to feed the ten lamps. In his new apparatus, Werdermann arranges them for tension, with a machine which gives less quantity but a greater electro-motive force.

In his new lamps (Fig. 82), the inventor has regulated the pressure of the lateral contact on the carbon point according to the pressure which this point exercises on the upper disc.

For this purpose the disc is placed on a beam kept in equilibrium by a counterpoise sliding on a horizontal rod; this rod is situated on the left of the point of suspension, and fixed in place by a screw. The beam carries a small arm, placed inside the globe, which exercises on the lateral contact a pressure in proportion to the pressure of the vertical carbon itself; this pressure opposes the ascending movement of the carbon point by wedging it between two jaws, of which one is fixed and the other movable.

This system forms, therefore, a check, whose equilibrium depends on the primitive adjustment of the counterpoise. In proportion as the carbon is wasted, the pressure on the disc diminishes, the lateral contact is slightly slackened, and permits the ascending motion of the carbon point.

Very slight contacts between the disc and the carbon point are obtained in this way; the pressure is never strong enough to produce the breaking of the point; the waste of the carbon is very regular; and the light shows a steadiness which is not to be found in the same degree in any other system.

The lamps act in tension on the same circuit. If one of them goes out from some reason or other, it must immediately be withdrawn from the circuit, and direct communication be established between the two terminals of the lamp, in order to prevent the extinction of all the other lamps in the same circuit. This result is obtained by the lever which presses against the lateral contact. When the

carbon point no longer presses against the disc, this latter begins to rock, and the lever presses against a metallic stop, which establishes a direct communication and short-circuits the lamp.

Joël's Improved Werdermann's Lamp.[1]—The light is produced, as was the case in Werdermann's system, by the heating to incandescence of the end of a small rod or pencil of carbon forming one electrode, which protrudes through a pair of contact jaws, and abuts upon a fixed cylinder of copper forming the other electrode. The carbon pencil consumes at the rate of two and a half to three inches per hour, for lights of 100 candle-power and upward, and is pushed forward according to the consumption. The length of carbon in circuit between the contact jaws and the fixed electrode is about three-quarters of an inch, and this, by the passage of the current, is rendered highly incandescent, chiefly, however, at that part near the copper electrode, where the pencil becomes pointed, and therefore more intensely heated. There is also, in addition to this, a glow or flame-like appearance from the sides of the consuming carbon to the copper electrode, the light thus apparently taking an intermediate position between the purely incandescent system and that of the arc. The heated point of carbon becomes curled at the tip in a peculiar manner, as though it were viscous, in shape somewhat like a mushroom where it wastes away, and is replaced by the gradual forward motion of the pencil.

The fixed electrode, which may be entirely of copper or with a graphite insertion, remains intact without any appreciable wear.

From *Nature*, 1881.

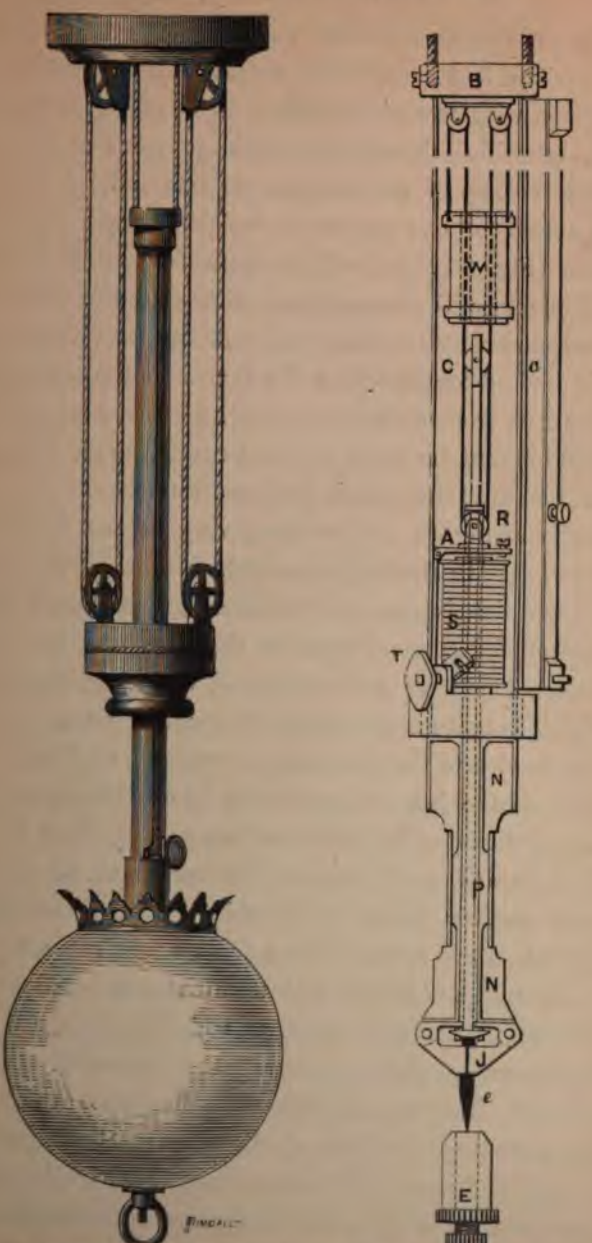


Fig. 83.—Joël's improved Werdermann's lamp (elevation and section).

The chief improvements in this lamp consist in the simplification and certainty of action of the mechanism in connection with the contact jaws for clamping the carbon pencil, by which means the lateral pressure of the jaws and the feeding of the carbons are attained by the combined action of one actuating weight, as shown in the diagram (Fig. 83). It will be seen from this that the lateral pressure is always proportional to the downward pressure, and may be varied to suit any conditions. The details devised for rendering the lamps in the same circuit independent from each other, and its general adaptability for interior and domestic lighting, constitute an important advance on anything which has gone before.

On referring to the sectional view of the lamp, E is the fixed copper electrode on which abuts the point of the carbon *e*, which is rendered intensely incandescent by the passage of the current between the jaws and the copper cylinder. The jaws are seen at J, clamping the carbon pencil. The actuating weight W, which gives both the feeding motion to the pencil as it consumes, and the lateral pressure to the jaws, is suspended by continuous cords to the top of the lamp B; the cords thus passing down through the weight and under one of the rollers at R, up again through another roller at R, and ending at the weight. The rollers R are attached to a light tube P, which passes down through a nipple N, and terminates in a flange under the horizontal arms of the jaws, and lifts them according to the leverage, thus producing the lateral pressure on the pencil. The top of this tube has also attached to it the armature A of an electro-magnet S, wound with fine wire, and arranged in a shunted circuit in such a manner that, as long as the normal condition of the light

is maintained, it is neutral; but if an arc should be accidentally formed between the carbon *e* and the copper E, the electro-magnet comes into action in opposition to the controlling weight, and frees the jaws from lateral pressure, thereby allowing the carbon pencil to descend freely and establish contact.

The carbon-holder (Fig. 84) is also arranged so that when the pencil is very nearly consumed, the lamp is automatically eliminated from the circuit by the lever at L making contact with the arm carrying the copper electrode. The stem or body of the lamp forms an important part of the whole, being formed of metal tubing in two semicircular halves, each half forming part of the electrical circuit, the current traversing one side, of which the jaws form part, passing through the carbon pencil to the copper electrode, and returning by the other side of the lamp.

Fig. 84.—Carbon-holder of Joël's lamp.

The two sides are kept closed mechanically (but insulated electrically from one another) by the latch and knob T (Fig. 83), which also automatically short-circuits the lamp when opened for the purpose of putting in fresh carbon, thus rendering it perfectly safe for handling. There are ingenious arrangements attached to this system for switching a lamp on or off, with resistances equal to that of the lamp; but upon these it is unnecessary to dwell, these adjuncts being common to many systems.

Professor Adams stated, at the Society of Arts, that with this system an illuminating power of 715 candles per horse-power could be obtained.

Incandescent lamps are very capricious. Difficulties arise from the extreme thinness and delicacy of the glass employed, leakage from defective sealing or fractures, the liability of the incandescent material to shake loose in its supports, and the great care required in manipulation. The Joël lamp is free from these objections, and as in lamps that are purely incandescent the heat is produced by the current only (the carbon not undergoing combustion by reason of the absence of oxygen), it follows that the incandescent portion cannot attain to so high a temperature as when the carbon consumes, and therefore the light must necessarily be of less power than that in the lamp described. In the workshops of the Electric Light Agency two of these lamps take the place of fifteen gas-jets, with highly satisfactory results. The carbons employed are five millimetres in diameter, and about one metre in length. The lamp burns for seven or fourteen hours, according to the dimensions of the carbon.

Various Lamps.—A number of lamps have been constructed since Reynier's and Werdermann's, founded on the incandescence of carbons with combustion. We only mention a few which differ from the two prototypes simply by some details of construction or arrangement.

Trouvé has constructed a lamp in which we find the ascending carbon, the rotating carbon abutment, and the carbon point wasted at its pointed extremity, as in Reynier's lamp. By employing carbon points made of very fine carbon, a light of several Carcel burners can be produced with six Bunsen elements.

In Ducretet's lamp, the carbon is pushed upwards by a column of mercury into which it is immersed.

This apparently simple arrangement, which is already indicated in Reynier's patent, has the drawback of giving off mercurial vapours, in spite of all the precautions that have been taken to prevent the heat of the incandescent carbon from reaching its surface.

Finally, Tommasi, in 1879, constructed a Reynier's lamp under the name of revolver lamp, in which a certain number of short carbons are arranged in a circle round an iron tube, three centimetres in diameter and turning on a pivot, A clockwork machinery successively places each of these carbons in the circuit, which gives to the light a certain duration. We shall refer to this lamp again in speaking of the use of batteries for the production of electric light (p. 239).

Lamps with Incandescence alone.

These lamps are constructed on the principle of raising the temperature of a moderate and infusible conductor by the passage of an intense electric current. The intensity of the light emitted by a heated body increases in a very large proportion with the temperature, and we need, therefore, only employ a substance with a very high point of fusion, to be able to raise it to a very high temperature. It is further necessary that the heat produced by the current should be concentrated within a very small space, to avoid the cooling which is so prejudicial to the quantity of the light produced.

The substances most commonly used for the production of light by incandescence are—platinum, an alloy of platinum and iridium, iridium, and carbon.

The first lamp with incandescent platinum dates back

as far as 1841, and was invented by Frederick de Moleyns, of Cheltenham.

The idea of employing iridium and its alloys is due to Pétrie, in 1849. In his patent, Pétrie gives the method of preparation of iridium intended for electric lamps.

The idea of using carbon for producing incandescence belongs to King, who patented it in 1845. According to Giffard, King was simply the agent of the real inventor, J. W. Starr, of Cincinnati.

Starr was the author of several philosophical works, and it was the great philanthropist, Peabody, who supplied him with the necessary funds for his experiments, which were made in this country.

Starr set up a candelabrum with twenty-six lights, symbolical of the twenty-six states of the Union. Faraday admired this first experiment very much, and Starr and King started for the United States soon afterwards. The day after their departure, Starr was found dead in his bed.

King pointed out in his patent the advantages of gas carbon, but in order to prevent its combustion, he placed it in a closed vessel from which the air had been previously exhausted. Two or more of these apparatus could be placed in the same circuit of a current supplied either by batteries or by magneto-electric machines.

In 1846, Greener and Staite took out a patent for a lamp similar to King's. To free the carbon from its impurities, it was treated with aqua regia.

After that, lighting by electricity completely fell into oblivion till 1873, when a Russian physicist, Lodyguine, took up the question. His researches earned him a prize from the St. Petersburg Academy of Sciences.

The advantages of carbon were then very clearly defined

by Wilde, who was entrusted with the report on the award of the prize. "Carbon has at equal temperature a greater radiating power than platinum, its calorific capacity is much smaller, so that the same amount of heat raises a carbon point to a much higher temperature than a platinum wire. Besides, the electrical resistance of carbon is about 250 times greater than that of platinum; the carbon may, therefore, be made much larger while raising the temperature as much as the metal. Finally, carbon is infusible, and its temperature may be raised without any danger of fusion."

Kosloff, of St. Petersburg, who came to France to work Lodyguine's patent, slightly improved the lamp, but without obtaining any satisfactory results.

In 1875, Konn constructed a similar lamp; in 1876, Bouliguine constructed another, with a single carbon.

All these apparatus, which have only found few applications, are described in detail in Fontaine's work on *L'Éclairage à l'Électricité.*

In 1879 appeared the American (Sawyer's) lamp, in which the incandescent carbon is placed in an atmosphere of nitrogen, in order to prevent its combustion.

In all these lamps, although the carbon does not burn in the true sense of the word, there is yet a sort of disintegration or evaporation which gradually destroys the incandescent carbon. This evaporation is, moreover, clearly proved by a deposit of sublimated carbon, in the form of a very fine powder, on the interior surface of the globes and the different interior parts of the apparatus. We had, therefore, good reason for saying, at the beginning of this chapter, that the aim pursued by the inventors, of saving the carbon from combustion, had not been completely attained.

Edison's Incandescent Carbon Lamp.—After having un-

successfully attempted to produce light for practical purposes, by the incandescence of platinum wires traversed by a current, Edison has had recourse to specially prepared carbon, and this special preparation constitutes the very essence of his invention.

Edison's lamp (Fig. 85) consists of carbon in the form of a horse-shoe of five to six centimetres in length, and three to four millimetres in width. This carbon is placed in a globe which has been so completely exhausted that the atmospheric pressure inside, according to Edison, does not exceed the $\frac{1}{100000}$th part of one atmosphere. The extremities of this carbon are fixed to two platinum pincers *a a*, which terminate in two wires of the same metal, connected with the exterior terminals.

Fig. 85.—Edison's lamp. 1, Paper carbon in form of a horse-shoe; 2, the entire apparatus.

This carbon is prepared by cutting small sheets of brown paper in the form of a horse-shoe; a certain number of these sheets are placed in an iron mould, which is gradually heated in a muffle; at the end of the operation, the muffle is maintained at a very high temperature during a certain time.

The volatile parts of the paper disappear, and a small texture of rather fragile paper carbon remains in the mould, which, when placed in the vacuum globe and traversed by an electric current, can, according to Edison, remain incandescent for an indefinite period, without breaking or deteriorating.

Edison has quite lately replaced his paper carbons by carbons made of fibres of bamboo, of the same horse-shoe form.

Swan's Incandescent Lamp.—This lamp was constructed several years ago, but has only given satisfactory results since Swan has made certain improvements in the preparation of his carbon filaments, which finally led to a complete success. Swan's lamps are now extensively used in this country. As regards their efficiency and illuminating power, it appears that fifteen lamps can be fed by one horse-power, and give a whiter and more brilliant light than other lamps of similar construction with the same motive power. Swan does not employ a special generator of his own; he uses sometimes Faure's accumulators, Siemens' or Brush's machines, and also De Méritens' alternating-current machine (p. 98). This latter seems to give particularly good results; for with continuous currents of great intensity the carbons sometimes break off at the positive pole.

Fig. 86.—Swan's lamp.

Fig. 86 represents the lamp with its mounting, which can easily be adapted for a supporting bracket or chandelier. It consists of a glass globe containing two platinum

carbon holders, with jaws and tightening rings, exactly like

Fig. 87.—Swan's portable lamp.

the brass crayon-holders which were formerly used fo

ng. The carbon filament, much thicker at the two nities, is bent in form of a flat helix, so as to form a in the centre of the glass globe, where an accumula- f heat is required.

ıe preparation of these filaments of carbon is some- different from that of Edison carbons. They ade of strings of cotton ten centimetres in ı, the ends of which are ened by winding some onal cotton round them. strings are immersed ute sulphuric acid (one

.— Reversed side of the stand of Swan's lamp.

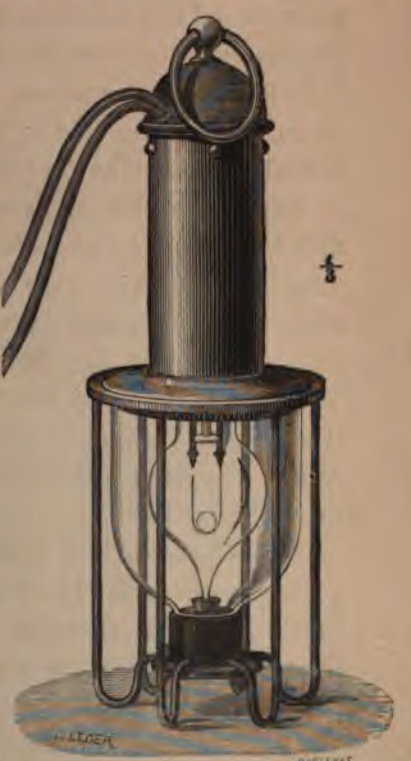


Fig. 89.—Swan's portable mining lamp.

of acid to two of water), and, after a certain time, ıe the compactness and hardness of parchment. They ıen placed in an earthenware vessel full of carbon dust. vessel is hermetically closed and raised to white heat certain time, after which the carbons are placed in the

lamps, which have been exhausted by means of the Sprengel pump, and electrically heated to incandescence in order to drive out all the gases which might be contained in the pores of the carbons. After this operation, which may last half an hour, the filament has become very hard, much more compact, and less voluminous, and is now ready for use. Its resistance varies from thirty to a hundred ohms, and the light it gives, under normal conditions, varies, according to Swan, from fifteen to twenty candles. In order to avoid the calorific effects at the points of soldering of the carbon-holders in the glass, these carbon-holders project considerably into the globe, and are joined at the lower end by a glass support. The platinum wires to which they are soldered are connected with the blades of a spring, which are to be seen in Fig. 86, on both sides of the mounting. To introduce this lamp into the stand or to withdraw it, it is sufficient to press the springs down with the hand, and remove the hand afterwards; electrical communication is thereby established.

Fig. 87 shows how Swan has adapted his lamp to a portable stand, and Fig. 88 shows the reversed side of this stand, with the electrical connections. Fig. 89 shows Swan's lamp for lighting mines.

Lane Fox's Lamp.—Fig. 90 gives a sectional view, and Fig. 91 a perspective view, of the lamp. The light results from the incandescence of a continuous conductor made of a filament of carbon. This conductor is of high electrical resistance, so that a comparatively small amount of electricity driven through it develops sufficient heat to produce incandescence. The filament is enclosed in a glass globe, from which all deleterious atmosphere has been as completely removed as possible.

In the diagram of the lamp, the curved line A represents the luminous conductor, which consists of a carbon filament prepared by baking a strong cotton thread or string in a hermetically sealed vessel at white heat. Conductors may be made in this manner with a resistance of several thousand ohms for only a few inches length.

In order to reduce this resistance and to produce a

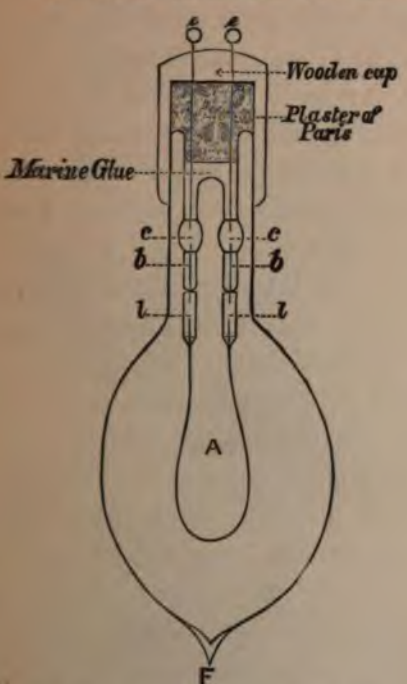


Fig. 90.—Lane Fox's lamp (sectional view).

Fig. 91.—Lane Fox's lamp (elevation).

harder and more durable carbon, Lane Fox adopted a plan, first suggested by Sawyer, of New York, of heating the conductor to incandescence whilst immersed in a hydrocarbon liquid or gas; but this process is not by any means essential. Referring again to the diagram, *l l* are carbon

cylinders, into which the ends of the carbon filaments are secured. A small hole is drilled through these cylinders, and into these holes the ends of the carbon thread fit tightly. A very good cement for fixing these carbons may be made out of plumbago and Indian ink. The platinum wires *b b*, which are about two centimetres long and 0·26 millimetre in diameter, are fused into the glass tubes *c c*, out of which they project into the globe about five millimetres. The carbon cylinders *l l* are secured to these projecting ends in the same way as to the carbon filament. The other ends of the platinum wire are surrounded with mercury at *c c*, into which dip also the copper conductors *e e*. The upper part of the lamp is entirely enclosed from the outer air by the glass blower.

Lane Fox's regulator for the intensity of the current is represented in Fig 92. It consists of an oscillating lever G, similar to the lever of an electric bell, which acts on a ratchet-wheel N. The axle of this wheel carries a toothed pinion placed between two toothed wheels R R' having a common axle. This axle carries at its extremity a rubber F, which moves over a circular range of contacts *c c*, corresponding to regularly increasing resistances, so that, according as the wheels R R' turn this rubber in one direction or another, a greater or less resistance can be introduced into the circuit or withdrawn from it. The axle of the two wheels moves longitudinally, and is directed by an electro-magnetic system consisting of two electro-magnets E' E' with a common armature A. This system is energized by a sort of relay with double contact E'' I, which sends through one or the other of the two electro-magnets E' E' a local current, and thus causes the toothed pinion to work into one or the other of the two wheels R R'.

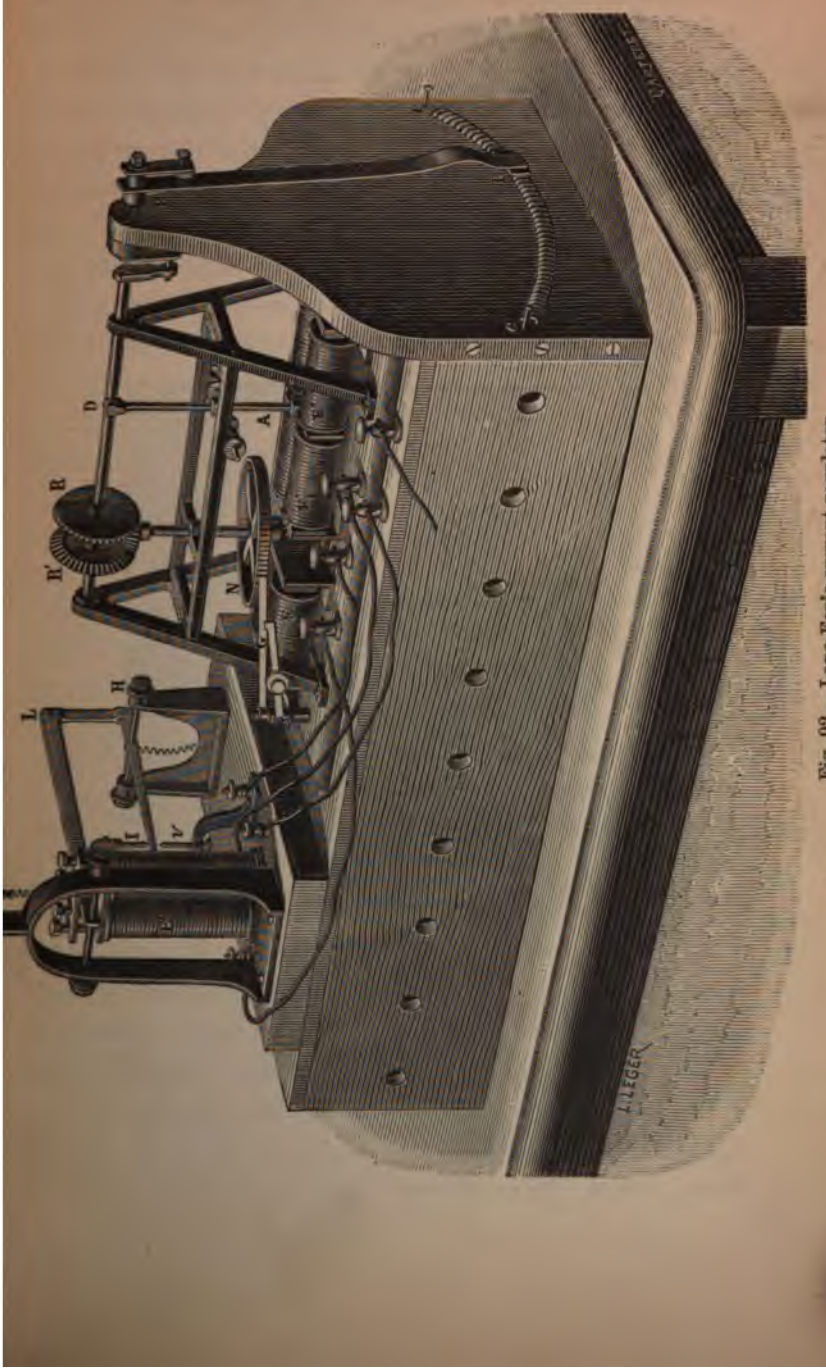


Fig. 92.—Lane Fox's current regulator.

The relay being placed in a shunt of the current supplying the lamps, it can act on the resistance of the circuit by means of the rubber F, which always re-establishes the original intensity. When this intensity increases beyond the useful point, the wheel moving the rubber in the direction of the increasing resistances is set in motion. In the opposite case it is the other wheel; so that the apparatus always oscillates between rather narrow limits.

The current is supplied by a Brush's machine.

Maxim's Incandescent Carbon Lamp.—The filament, which

Fig. 93.—Maxim's lamp.

is of the shape of an M (Fig. 93), is made of carbonized cardboard. The globe is exhausted, and a certain quantity of hydro-carbon vapour (gazoline) introduced, then the globe is again exhausted whilst the current passes, and the operation repeated until all the air is expelled. It has been proved by experience that by the passage of the

current the rarefied vapour of gazoline has a renovating effect, by depositing its carbon on the most incandescent, that is to say the thinnest, parts of the filament. The filaments are connected to the platinum pincers by means of soft carbon, which gives an excellent contact. The conductors are sealed into a special enamel which has nearly the same coefficient of expansion as platinum; this prevents cracks and contributes to the tightness of the apparatus. The lamps are fixed to an ebonite mounting, which terminates in a pedestal of German silver; this latter can be screwed on a gas-bracket instead of an ordinary burner.

Incandescent Lamps with Platinum Wire.—It has been mentioned on p. 224 that the first lamp of this kind was constructed by De Moleyns, in 1841, and a similar lamp by Pétrie, in 1849.

In 1857, De Changy invented a system, permitting the divisibility of the electric current. According to a letter addressed by M. Jobard, Director of the Musée Industriel Belge, to the Académie des Sciences in Paris, Changy obtained, with a battery of twelve Bunsen elements, twelve lights, of great steadiness and independent of each other; but the terms of the patent are so vague, that it is impossible to understand the exact working of Changy's apparatus.

Edison's Lamp with Incandescent Platinum Wire.—This lamp consists of a spiral platinum wire[1] traversed by an electric current. To prevent the fusion of the wire, a metallic

[1] Most of the incandescent metallic lamps have spiral wires. The object of this arrangement is to concentrate the heat of the current within a small space, in order to raise the temperature of the body to its maximum, and consequently to obtain from it a large quantity of light. A platinum wire, traversed by a current of given intensity, is carried to red heat when stretched out, whilst it reaches white heat when coiled into a spiral.

rod, placed inside the spiral and heated by it, establishes by its expansion a direct communication; a short circuit is formed between the two terminals of the apparatus, and weakens for a short period the current traversing the luminous spiral. The spiral is cooled, and also the metallic rod, which contracts and thereby breaks the short circuit. The current traverses anew the spiral platinum, and the same series of phenomena are exhibited. But as these phenomena of heating and cooling are very rapid, Edison's apparatus was little else but an electrical vibration instrument.

In Lontin's lamp the adjustment was effected by the variation of intensity of the current, that is to say, by the cause and not by the effect.

Maxim's incandescent platinum lamp was similar to that of Edison; the adjustment was likewise effected by the expansion of the foil.

Various Systems of Lighting.—In certain special cases, particular systems of electric lighting have been used, of which we must say a few words.

Gaiffe has combined a lighting system for mines, consisting of a Ruhmkorff coil and a Geissler's tube, surrounded by a second thicker tube to protect it against shocks. The miner carries on his back the battery and the coil packed in a small knapsack. The lamp is held in the hand by flexible wires of a certain length; it can also be suspended, if required.

Planté has proposed the use of his secondary battery for the same purpose. Jablochkoff used kaolin blades in 1878, which he heated by high-tension currents, developed in an induction coil by the alternating currents of a Gramme's machine. The light is very steady and very beautiful; it

varies, according to the power of the source, between two and fifteen Carcel burners. It is, in reality, an incandescent light, but the blade must previously be heated to make a conductor of it, by joining the two electrodes which are connected with the kaolin blade, with a piece of gas carbon. A spark is passed at a given point, the carbon becomes red hot, transmits its heat to the nearest particle of kaolin, and the current passes, first on a small area, which gradually enlarges as the carbon slides along the kaolin. Radiation makes the luminous band appear much larger than it really is. The waste of the kaolin blade is imperceptible, and does not exceed one millimetre per hour.

Jablochkoff has obtained even better results with this system by interpolating in the circuit of an electro-magnetic Alliance machine a condenser and a kaolin blade. In this case, he does not employ an induction coil; the kaolin blade is fed by successive discharges of the condenser.

Some inventors have proposed the use of certain powders rendered incandescent by their passage through a voltaic arc. Way lit up threads of mercury traversed by the current; the mercurial vapours given off by this lamp poisoned the inventor.

Two Americans, Molera and Cebrian, have proposed to create a small number of centres, and to distribute the light produced by these centres, by means of lenses and reflectors, along the buildings and underneath the floors for domestic purposes—a most fantastic idea, quite in the American style.

Of all these more or less successful attempts, there remain at present only two general methods of electric lighting—

1. The voltaic arc, by regulators and candles.

2. Incandescence, by carbon, platinum, iridium, and other bodies of inferior conductivity.

CHAPTER IV.

THE APPLICATIONS OF ELECTRIC LIGHTING.

THE applications of the electric light daily assume more importance, and it would lead us too far to enumerate all the experiments made in this direction since Deleuil and Archereau first attempted, in 1842, to use it for practical purposes.

We shall confine ourselves to the description of some of the most important, from the powerful light of light-houses, equal to 2000 Carcel burners or more, to incandescent light whose illuminating power scarcely attains $\frac{1}{10}$ of a candle, and which is used in surgery for lighting obscure cavities.

THE ELECTRIC SOURCES CONSIDERED FROM THE POINT OF VIEW OF THEIR APPLICATION FOR LIGHTING PURPOSES.

After having described the different modes of producing the electric current, and the apparatus which transform the electricity they receive into light, we have to examine the value of each of these electrical sources with regard to the luminous centre which it is destined to feed, before entering upon the description of the various applications which have been made.

We shall follow, in this short review, the same order that we have adopted for the description of electric generators.

Liquid Batteries.—Although, theoretically, electric light can be produced by any battery, provided we have at our disposal a sufficient number of conveniently arranged elements, there are very few liquid batteries capable of producing light easily and inexpensively. The great strides electric lighting has lately made only date from the use of powerful machines—about ten years ago.[1] The introduction of the Jablochkoff candle, in 1876, gave a new impetus to inventors, and especially to speculators and speculations. Before the employment of machines, the Bunsen battery in its different forms was used for lighting on a large scale, with Serrin's regulator; for optical projections and stage purposes, with Foucault's and Duboscq's regulators. It is still used at the Paris Opera-House for scenic effects, but there is very little doubt that it will, before long, be replaced by an electric machine. The use of batteries for electric lighting is now exclusively restricted, with a very few rare exceptions, to the lecture-room, the laboratory, and for optical projections.

Quite apart from the question of expense, which forbids the use of batteries, the manipulation of a large number of elements—forty at least of moderate strength are required to produce a somewhat stable voltaic arc—presents serious difficulties and drawbacks, and the vapours given off are very injurious into the bargain.

In spite of these numerous drawbacks, Tommasi attempted, in 1879, to render the Bunsen battery available

[1] The application of the Alliance machines for the electric lighting of the lighthouses of La Hève has existed since 1863.

for domestic lighting. Tommasi's element, which presents no particularly novel features, in spite of the high-sounding name of "perpetual battery" given to it by the Abbé Moigno, does not in any way fulfil the aim of its inventor, or of the company working the patent. We have not heard of a single application of this system of lighting, which was established with a capital of two millions of francs.

The same may be said of Cloris Baudet's so-called impolarizable battery. Émile Reynier, more than anybody else, was interested in finding a practical battery which, if applied to his lamps, would have opened for them an immense field of application. After having tried all the known batteries capable of giving any results, he has come to the conclusion that none of them could satisfy the conditions required for the application of electricity for domestic lighting. Tommasi's and Cloris Baudet's batteries have not modified this conclusion. The field, therefore, remains open to inventors, who may be more successful in the future.

Thermo-Electric Batteries.—The application of thermo-electric batteries for lighting is of a very recent date. The credit of having first used these appliances for the said purpose, in 1879, is due to Clamond.

With the battery of 6000 elements, described on p. 48, Clamond has worked two Serrin's regulators specially constructed for this battery, and has obtained a light varying from thirty to fifty Carcel burners for each regulator.

This is a very promising result, although only moderate from an economical point of view.

Secondary Batteries.—Although the secondary battery is not an electric generator in the proper sense of the word,

it can render services in several special applications, of which we will only quote a few.

Secondary batteries can produce, after having been charged for a few minutes with two Bunsen elements, a voltaic arc of a few seconds' duration and of great intensity, on employing a sufficient number of secondary couples. This light can be used for signals, photography, and generally in all cases where only a short period of lighting is required.

To state the problem from a more comprehensive point of view, secondary batteries will enable us, if we only succeed in increasing the storing power of the elements, to utilize natural forces, such as waterfalls, winds, and tides, for electric lighting by employing the methods which have been mentioned with reference to secondary batteries.

It is no mere Utopian fancy which holds out the promise of similar applications; for they rest on a philosophical principle—the turning to account of wasted, or rather non-utilized forces; and on a series of apparatus which all exist in reality—windmills, turbines, electrical machinery, and storage batteries.

The question once put, the solution of a problem of such vast importance and such general interest will not be long deferred.

Continuous-Current Machines.—All the machines which have been described can be applied to arc lamps. Most of the inventors, however, use a special regulator with their machines.

With Gramme's machines, Serrin's regulator is commonly used; Siemens' differential lamps are fed by his machines; the lamps of Brush, Wallace-Farmer, and Bürgin are used with the regulators of their inventors.

In most of the arc lamps which are fed by continuous

currents, one single lamp only is placed in the circuit of the machine.

For incandescent lighting, the same generating machine can feed several lamps mounted, as the case requires, for tension, derivation, or series. These machines allow even of mixed lighting; which means to say, that, with a single electric generator, two Reynier's lamps and a Serrin's regulator in tension in the same circuit, can be fed without sensibly weakening the light which this latter would give without the interpolation of the lamps.

Thus one powerful centre, and one or two smaller centres, are produced with the same machine.

Alternating-Current Machines.—Although a certain number of regulators can be fed by these machines, they are generally reserved for the division of light, electric candles, and division regulators. All candles, without exception, are fed by alternating currents, and the necessity of equally consuming the two carbons makes the use of these machines absolutely indispensable. Moreover, their larger tension allows of a larger number of lamps being placed in the same circuit. A Gramme's machine, for instance, can feed from three to six candles in tension. Rapieff can feed three of his lamps with the same arrangement. Siemens' machines feed ten differential lamps, and Lontin's machines as many as twelve Lontin's or Mersanne's regulators in a single circuit.

These machines are often fractional themselves, and feed several circuits. A striking example of division is Gramme's machine feeding sixty Jablochkoff candles, arranged in distinct circuits of five candles each.

It will be seen, from all that has been said, that there is no electrical source which could be recommended for universal

application. Special requirements must determine the choice, as, for instance, the number of light-giving centres, their intensity, the greater or lesser need of steadiness, of simplicity, or economy. In the few examples of practical applications which we are now going to describe, we shall mention the source employed, giving, as far as possible, the reasons which have led to the choice of a special source.

The Edison System. — The Edison dynamo-electric machine differs from other machines of the same description chiefly by the construction of its armature. The usual insulated wire coils are replaced by longitudinal bars of copper, of trapezoidal section, insulated from each other by prepared brown paper. A number of well-insulated flat copper rings are strung over the central shaft at each end of the armature, and the arrangement is such that in each case two bars which are diametrically opposite to one another are connected by a ring, and all the bars are included in one continuous electric circuit.

The conductor for conveying the current in the Edison street-lighting system consists of a metal tube about three inches in diameter, containing a cheap insulating substance, and traversed by two half-round copper conductors about an inch in diameter. This main pipe can be as long as required, is buried along the main streets, and at the side streets it has derivations branching off, to supply the current to the places it is required to illuminate.

The branching off is effected by means of an iron box into which the conductors are led and connected to insulated terminals, to which are also connected the branch wires.

The connection of the lower main wire with the right-hand branch wire is not direct, but is made through the medium of a short conductor; this latter is of lead, and

acts as a safety-valve. If the strength of the current flowing out to the branch should, from any cause, become too great, then the leaden conductor melts and causes a disconnection. The whole box is hermetically sealed up, so as to keep the inside perfectly dry. The conductors which are led off into the houses are of small diameter (about two or three millimetres), and are joined on to the branch conductors much in the same way as the latter are joined to the main conductors.

The forms of the Edison incandescent lamps are very numerous. In the simplest form, which is almost identical in construction and shape with Swan's and Lane Fox's lamps, the incandescent carbon is formed by a single horse-shoe, made of carbonised bamboo-fibre.

Lamps have also been constructed with a double horse-shoe, and with four horse-shoes coupled in series, or for quantity as occasion may require.

For coal-mining purposes, Edison has designed a lamp very similar to Swan's mining lamp, in which the connections are kept covered with water contained in a glass vessel, so that contact of gas in the mine with any part of the lamp likely to become broken is impossible.

In cases where it is required to be able to diminish or increase the light given by a lamp, the arrangement consists simply of a number of carbon bars of different sizes, any one of which can be inserted in the circuit by turning a disc-piece, which makes a contact with the carbon, giving the necessary resistance. The whole set of bars are covered by a perforated cylinder, which allows the air to circulate and keep the bars cool.

The regulation of the current strength is effected by means of a system of testing. The arrangement consists of

a rheostat in circuit with the inducing magnets of the dynamo machine. By this means the action of the latter can be regulated at will by introducing in the circuit referred to more or less resistance according as the current in the circuit of the lamps is observed to be increasing or decreasing from its normal strength. The resistances of the rheostat are made of thick wire, and are wound on open frames, to avoid heating as much as possible.

Instead of keeping the current constant by the galvanometer observation, this can be done by observing the photometric value of the light obtained from a lamp placed in the circuit.

Lighting of Lighthouses.—On the 26th of December, 1863, the lighthouses of La Hève were for the first time lighted by electricity with the Alliance machines.

In this country, Holmes' machines, which are very similar to the Alliance machines, were used very soon after for the same purpose, but now dynamo-electric machines are used in preference, and this is explained by the fact that, for equal power, dynamo-electric machines are less heavy, less expensive, and less cumbersome than magneto-electric machines. The currents used at the lighthouses of La Hève are alternating; at the Lizard Point continuous currents are used.

Under normal atmospheric conditions, Alliance machines with four discs give a range of vision of thirty-eight kilometres (about twenty-five miles), and machines with six discs, a range of fifty kilometres (about thirty miles).

Lighting of Vessels.—The electric light can also do good service in the lighting of vessels where steam is available as motive power, and the installation of a dynamo-electric machine presents no difficulties.

In men-of-war, the lighting apparatus is generally rendered more effective by the addition of projectors, which throw the light in a given direction, and enable the observer to sound the horizon on all sides. The dynamo-electric machines are worked by small Brotherhood motors with three cylinders. Hand regulators are used in the French navy, which allow of a rapid extinction and relighting, and of an instantaneous regulation of the intensity of the light thrown on a given point.

Signals.—The electric light will also do good service for night signals, either by extinguishing the light, or by a successive covering and uncovering of the light-giving centre.

The operation is effected at a distance by an ingenious contrivance of De Mersanne, which enables the operator not only to produce the successive lighting and extinction, but also to control the effect without seeing the lamp.

Electric Light in Collieries.[1]—The first practical application in the United Kingdom of the electric light to the illuminating of coal-mines was made on the 9th of August, 1881. The Garnock Colliery, near Hamilton, Lanarkshire, belonging to Mr. J. Watson, has been fitted with Swan's incandescent lamps specially arranged with outer lanterns of stout glass, air-tight, and provided with steel guards. The workings in which the lamps are fixed are 118 fathoms, or 708 feet, below the surface. Twenty-one brilliant little lights placed at the pit-bottom, in the roads, and at the actual face of the seam where active operations are in progress, supply an illumination of a very different character from the dismal glimmer of an occasional Davy. The electricity was generated by a dynamo-electric machine at the surface,

[1] From *Nature*, 1881.

worked by a special twelve horse-power engine, and conveyed by two cables, first along telegraph poles to the pit-mouth, then down the shaft to the workings, in one section to a distance of half a mile. The overhead wires are naked copper wires of three-eighths of an inch diameter, while those below ground are carefully insulated, and in the shaft are protected with an outer tube of galvanized iron. At suitable points of the circuit, safety air-tight switches, the invention of Messrs. Graham, of Glasgow, are inserted to afford control over individual lamps.

An experiment was made with a lamp to test whether, in the event of its being broken by accident, a surrounding atmosphere of explosive gas would or would not be kindled by the strip of red-hot carbon before it had time to cool. Into a box containing about three cubic feet of explosive gas, a single lamp, removed from its outer protecting case of stout glass was placed, and the current was turned on. The fragile bulb enclosing the incandescent carbon thread was then purposely broken, when the gas enclosed in the box immediately exploded. No such occurrence could possibly happen if the protecting case of stout glass is properly constructed. The risk of accident must be considered immensely less than that of the ordinary Davy lamp, especially when it is remembered that, with the brilliant light of the electric lamps, they need no longer be carried in the hand or set down upon the floor near the actual spot where the coal is being got, but can be fixed overhead at a safe distance against the wall of the mine. The ease with which the lights can be turned out during the firing of a blast is another point in their favour.

It cannot be doubted that the universal adoption of electric light in fiery mines would reduce the death-roll of

persons killed by explosions of fire-damp in Great Britain to one-tenth of its terrible proportions, which in 1880 reached 499 persons. It is to be hoped that before long the adoption of electric lighting will be made compulsory by Act of Parliament. The colliery owners themselves will discover, when driven to this course by compulsion, that in the long run they effect an economy by discarding the clumsy and unsafe "safety" lamp, which will soon be numbered, with the "flint-mill," among the relics of the past.

Application for Warlike Operations.—The light can be applied in war, either to furnish signals or for illuminations of longer or shorter duration, as, for instance, for reconnoitring of fortifications, firing of batteries, to prevent a surprise on the opening of a trench, for lighting up a breach, etc. These different applications have been studied by Martin de Brettes, in an interesting pamphlet published by Du Moncel in his *Exposé des Applications de l'Electricité*, to which we refer our readers.

The use of dynamo-electric machines worked by locomotive engines facilitates these operations.

For war signals, Gramme has constructed a machine of small dimensions, which can be worked by four men; an intensity of fifty Carcel burners (800 candles) can be produced, which is quite sufficient for the exigencies of war.

Electric lamps have been introduced for lighting railway carriages and steamers. Quite recently the carriages of the Pullman train between London and Brighton were lighted with Swan's lamps supplied by a Faure's storage battery.

Lighting of Workshops and Factories.—For the illumination of large areas the arc light is the most convenient, and has lately found a large number of applications in this

direction, more especially so where the factory has already a powerful steam or hydraulic motor, from which a few horse-powers can be taken for the purposes of lighting; the light, of course, ceases at the same time as the work itself. The first installations were made with regulators of one focus and with Gramme's or Siemens' machines; a separate machine and transmission were then required for each focus. During the last few years powerful machines and division regulators have come into more general use—a machine sufficiently powerful to supply all the centres, either, as is most generally the case, in one circuit or in a small number of circuits, is used in preference; a considerable saving is thereby realized in the installation of transmissions, of conductors, and in the working expenses. The light-centres thus obtained are less powerful than the original single-focus regulators, but for equal expense they are preferable, because they allow of a more perfect division and diffusion of light.

This diffusion is almost indispensable in most of the applications. Thus at the head telegraph office at Brussels, the large instrument-room is lighted by means of two centres, arranged in such a way that they cannot be seen from any part of the room.

Incandescence pure and simple will also render good service for lighting workshops, studios, etc., by introducing a soft and mellow light into localities where the arc light has not yet been able to penetrate. A mixed system of lighting will, no doubt, be effected before long, answering all practical purposes, and gas will no longer be used in factories which have sufficient motive power, and the electric arc, as well as the incandescent light will be found more economical.

The Electric Light at the Opera.—Electric light was used at the theatre for the first time in 1846, for lighting up the skating scene in Meyerbeer's *Prophet*, and created great astonishment and admiration.

For nearly twenty years Duboscq has been in charge of the electric lighting department at the old Opera-House in Paris, and it is he who has organized, only on a much larger scale, the same department at the new Opera.

The electric light is produced in that magnificent theatre, built by Charles Garnier, by 360 Bunsen elements set up in a large room on the ground floor of the building. This is one of the few instances where the battery is still used as an electric generator on a large scale. But this isolated application, which is no longer in keeping with modern progress, will, no doubt, before long give way to some more practical system.

The Electric Light at the Hippodrome.—The electric lighting of the Hippodrome consists of 120 Jablochkoff candles and twenty-one Serrin's regulators, which in full work expend a force of 160 horse-power. The application of two different systems, candles and regulators, necessitates the employment of two systems of machinery, both invented by Gramme.

The 120 candles are fed by three alternating-current machines of twenty candles each, and by a machine of sixty candles. Each of the regulators is fed by a Gramme's machine with continuous current. Each continuous-current machine can only feed one regulator at a time; but, by means of a commutator, different parts of the circus can be lit up according to the requirements of the performance. For carriage races and equestrian exercises, the regulators of the circumference are lit; for ordinary performances,

the regulators light up the centre of the ring; for performances in the air, another system is used.

All these changes are effected with remarkable rapidity and ease. An arrangement must be mentioned by which some saving has been effected in the original outlay. The machines of the regulators have no return wire to complete the circuit; the return is effected by the framework of the Hippodrome, which, wholly of iron, serves as a conductor, and completes the circuit.

The transmissions are so arranged that the speed of each machine is rendered independent of the others, and consequently proportionate to the distance which separates the lamp from the electric generator. For this purpose, the diameter of the driving wheel need only be specially adapted to each machine.

The division machines used are Gramme's machines with alternating currents. The bobbins are arranged in four circuits, feeding five candles each. These machines make 660 revolutions per minute; their inductors are fed by a Gramme's machine of the same type as those employed with Serrin's regulators (workshop type); the charging machines make 600 revolutions per minute.

The machine supplying sixty candles feeds twelve circuits of five candles each, and only performs 540 revolutions; its charging machine has a speed of 1100 revolutions; whilst those machines supplying twenty candles each expend sixty horse-power. The chief engineer, M. Geoffroy, estimates that the machine supplying sixty candles only expends fifty horse-power. This proves again the marked advantage of powerful machines over small ones. The work expended varies between 160 and 170 horse-power. The motive power is supplied by two com-

pound steam-engines of 120 horse-power each. Two fly-wheels of 2·6 metres in diameter transmit the motion to two axletrees by means of indiarubber straps of forty centimetres width; the axletree carries a drum, and over the drum passes the horsehair strap which transmits the motion to the electric machines. Three boilers of superior make, of seventy-five horse-power each, complete the system. The extinctions, so frequent at the outset, become more and more rare every day, thanks to M. Geoffroy's exertions.

A few words must be said on the question of expense, which, of course, is a very important factor. The electric lighting of the Hippodrome, whose brilliancy and beauty are undeniable, costs 250 to 260 francs per night. The lighting with gas amounted to 1100 to 1200 francs per night a few years ago, and did not produce a very brilliant effect.

The considerable saving effected in this instance is due to the large scale on which the new system is carried out; for smaller operations, electric light would be more expensive than gas.

Application of Electric Light to Horticulture by William Siemens.[1]—On the 1st of March, 1880, Siemens communicated to the Royal Society a paper "On the Influence of Electric Light upon Vegetation, etc.," in which he arrived at the conclusion that electric light was capable of producing upon plants effects comparable to those of solar radiation; that chlorophyll was produced by it, and that bloom and fruit, rich in aroma and colour, could be developed by its aid. The experiments also went to prove that plants do not, as a rule, require a period of rest during the twenty-four

[1] From *Nature*, 1881.

hours of the day, but make increased and vigorous progress if subjected (in winter-time) to solar light during the day and to electric light during the night.

During the whole of the winter of 1880–81, Siemens continued his experiments on an enlarged scale. The arrangement used for the experiments consisted of a high-pressure steam-engine of six horse-power, which gave motion to two dynamo machines (Siemens D) connected separately to two electric lamps, each capable of emitting a light of about 5000 candle-power. One of these lamps was placed inside a glass house of 2318 cubic feet capacity, and the other was suspended at a height of twelve to fourteen feet over some sunk greenhouses. The waste steam of the engine was condensed in a heater, whence the greenhouses take their circulating supply of water, thus saving the fuel that would otherwise be required to heat the stoves.

The experiments were commenced on October 23, 1880, and were continued till May 7, 1881. The general plan of operation consisted in lighting the electric lights, at first at six o'clock, and during the short days at five o'clock, every evening except Sunday, continuing their action until dawn.

The outside light was protected by a clear glass lantern, whilst the light inside the house was left naked in the earlier experiments, one of Siemens' objects being to ascertain the relative effect of the light under these conditions. The inside light was placed at one side over the entrance into the house, in front of a metallic reflector, to save the rays that would otherwise be lost to the plants within the house.

The house was planted in the first place with peas, French beans, wheat, barley, and oats, as well as with

cauliflowers, strawberries, raspberries, peaches, tomatoes, vines, and a variety of flowering plants, including roses, rhododendrons, etc. All these plants being of comparatively hardy character, the temperature in this house was maintained as nearly as possible at 60° Fahr.

The early effects observed were anything but satisfactory, and it was only after a lantern of clear glass had been put round the light, for the double purpose of discharging the chemical products of the arc and of interposing an effectual screen between the arc and the plants under its influence, that satisfactory results were obtained. Thus peas which had been sown in October produced a harvest of ripe fruit on February 16, under the influence, with the exception of Sunday nights, of continuous light. Raspberry stalks, put into the house on December 16, produced ripe fruit on March 1; and strawberry plants, put in about the same time, produced ripe fruit of excellent flavour and colour on February 14. Vines which broke on December 26, produced ripe grapes, of stronger flavour than usual, on March 10. Wheat, barley, and oats shot up with extraordinary rapidity under the influence of continuous light, but did not arrive at maturity; their growth, having been too rapid for their strength, caused them to fall to the ground, after having attained the height of about twelve inches.

It has likewise been proved that plants grown and brought to maturity under the influence of continuous light, are capable of reproduction.

The result of these experiments is that, although periodic darkness evidently favours growth in the sense of elongating the stalks of plants, the continuous stimulus of light appears favourable for healthy development at a greatly accelerated

pace through all the stages of the animal life of the plant, from the early leaf to the ripened fruit. The latter is superior in size, in aroma, and in colour to that produced by alternating light, and the resulting seeds are not, at any rate, devoid of regerminating power. Further experiments are necessary before it would be safe to generalize, nor does this question of diurnal rest in any way bear upon that of annual or winter rest, which probably most plants that are not so-called annuals do require.

Siemens has found useful employment during the day-time for the power-producing machinery by applying the electric energy to farming operations (including the pumping of water, the sawing of timber, and chaff and root cutting), at various distances not exceeding half a mile from the source of power; thus reducing indirectly the cost of the light during the night-time. Siemens has calculated that the total cost per light of 5000 candles amounts only to sevenpence per hour, provided the power of the dynamo-machine is also utilized during the day-time.

Application of the Secondary Battery for Galvano-caustic and for Lighting of Dark Cavities.—The property of the galvanic current of heating inferior metallic conductors to redness was utilized in surgery by John Marshall in 1851, by Leroy d'Etiolles in 1853, Mideldorpf in 1854, Broca in 1856, etc.

The lighting was attempted later than that; in 1867, Dr. Bruck, a dentist at Breslau, brought out an apparatus for lighting up the buccal cavities, to which he gave the name of stomatoscope. A little later, Dr. Millot, in France, made numerous experiments for lighting up the stomachs of animals at the École Pratique, in Paris.

The attempts were not successful, on account of the

inconstancy of the electric source (Grove's and Bunsen's couples), which necessitated the use of very thick platinum wires, in order not to expose them to a permanent volatilization. Luminous effects were obtained, it is true, but at the same time calorific effects of such intensity as to render this method of lighting impossible. A circulation of water was established to counteract the heat produced, but the apparatus were too cumbersome and difficult to handle, and have not been adopted in practice.

Gaston Planté indicated, as early as 1868, the application of the secondary battery for this purpose, and carried it into effect in 1872.

In 1873, Dr. Onimus performed, with Planté's apparatus, cauterization of the lachrymal gland on seven or eight individuals, without re-charging the apparatus. Trouvé has added to Planté's apparatus a rheostat with a platinum wire for the graduation of the intensity of the current according to the diameter and the length of the platinum wire used for lighting or for cauterizing. He has also added a galvanometer with two circuits, to control the charge of the secondary couple and the condition of the charging battery.

This apparatus is called a polyscope, and is represented in its box in Fig. 94.

By means of the rheostat, platinum wires of from $\frac{1}{15}$ to $1\frac{1}{2}$ millimetre in diameter can be heated to the point of fusion for several hours without ever exceeding that point. Trouvé uses, instead of platinum spirals, small wire flattened in the middle, so as to form a small incandescent disc. The luminous power is thereby sensibly increased, as has been proved by Captain Manceron, in his experiments of lighting up the interior of guns at Saint Thomas d'Aquin.

For lighting of cavities, Trouvé employs a series of spherical reflectors, concave or parabolic, with or without mirrors. A handle and conducting wires connect these reflectors with the reservoir at C and D.

Fig. 95 represents a reflector with a handle for lighting up the throat and other obscure cavities.

At the fiftieth anniversary of the École Centrale, in 1879, Trouvé illuminated for

Fig. 94.—Trouvé's polyscope.

Fig. 95.—Reflector with handle.

the first time, with a special polyscope, the interior of a pike. Nothing could be more interesting than to see this transparent fish, which seemed in no way concerned on being turned into a sort of Chinese lantern. The intensity of the light obtained by comparatively so feeble a source is

easily explained by the law of the square of distances. The most favourable conditions for seeing an object distinctly are to place the luminous point very close to the object, and keeping the eye in darkness.

Various Applications.—We have only space to mention a few of the numerous and varied applications where electric light has rendered good services, and services which gas-light could never have performed.

It is employed in mines, either with Geissler's tubes, as in Dumas and Benoit's apparatus, or with Serrin's regulators and Gramme's machines, as in the slate-quarries at Angers. Before the invention of dynamo-electric machines, the electric light had already been used, with batteries, for the construction of certain public buildings, as, for instance, the Imprimerie Nationale, in 1868–69. The application of electric light for lighting railway stations, workshops, and public squares has become so universal that it needs no further comment. We also find it in churches, theatres, libraries, and skating rinks; it is used for hydraulic works under water, for the lifeboat service, in the air, on the highest buildings.

We must not forget the fanciful applications which certain very enthusiastic inventors keep in store for the electric light. Some of them have proposed to light a whole town by setting up, in some elevated spot, a light of unsurpassed splendour—a sort of electrical sun. A study of the law of the square of distances will soon destroy this illusion, quite apart from the difficulties which the creation of an electrical focus of sufficient intensity would present. Others have proposed to light carriages with electricity, by utilizing the motion of the vehicle itself, and for several days an advertising carriage, founded on this idea, was

driven about Paris. But—and this is a terrible "but"—when the carriage stops the light is extinguished, just at the moment when it is most wanted. The electricity might, of course, be stored up and expended during the time of stoppage, but in that case the carriage would be considerably overcharged, and we may well say the game is not worth the candle.

It has also been proposed to employ electric light for fishing. Experiments made on the Lake of Enghien have proved that the method was excellent—to drive away the fish frightened by this dazzling light. It was certainly not the fish that were caught by this experiment.

Amongst the more serious applications must be mentioned the use for projections in teaching, the reproduction and enlargement of microscopical photographs which rendered such signal service during the war of 1870; the reproductions of enlarged photographs, such as linography, so well executed by Pierre Petit; photography at night, practised by Van der Veyde of London, and Liebert of Paris.

We are now going to examine the advantages and drawbacks of electric light, and say a few words about the expense of installation and working; we shall then have a very clear conception how far the problem of the division of light has progressed towards its solution, and what a great future there is in store for it, provided this progress, as we have every reason to expect, continues at the same rate it has followed for the last few years.

Advantages and Drawbacks of Electric Light.—Fontaine, in the preface of his work on electric lighting, justly remarks, "It is incontestable that when a light of great intensity is required at a certain point, as, for instance, in a

fort for watching the enemy, in ports for preventing the destructive effects of torpedo-boats, in lighthouses for guiding the navigators, electric light is not only the most economical of all, but often the only practicable one. It is equally certain that for a large dockyard as that at Havre, or for a vast enclosure like that of the Hippodrome, where it is impossible to suspend lighting apparatus and to place candelabra in the ring, the electric light is the only possible one, the only one which can replace the absent sun.

"We may, therefore affirm, that electric lighting has its own domain, where it need fear no opposition from any other system."

We have here the electric light as a focus of great intensity, and we shall examine it presently from the point of view of division of light.

Another advantage of the electric light is the feeble quantity of heat produced by the voltaic arc. Laurbé has calculated[1] that for equal light the voltaic arc produces 150 to 200 times less heat than a gas-burner. This is a very valuable property, which is very much appreciated in a great number of applications where the heat produced by the gas is really unbearable. An additional advantage is that it deprives the surrounding air of a very small quantity of oxygen—the oxygen required for the combustion of the carbons—and, therefore, does not vitiate the atmosphere. For tunneling it will prove invaluable, as has already been proved in the excavations for the Channel tunnel. For this application the question of expense of the motive force will be of secondary importance, because natural forces are generally utilized in these cases, and more compressed air is allowed to escape for the ventilation of

[1] See *La Lumière Électrique* of the 15th of November, 1879.

the galleries than the electro-dynamic machines necessary for the feeding of these divided centres would consume.

Another advantage of the electric light—an advantage which is, however, contested by a great many impartial persons—is its tint, which permits the distinction of the most delicate shades of colours. Contrast alone imparts to it that pallid tint which is considered objectionable, and we have only to look at the same time at a gas flame and a Jablochkoff candle to see how little foundation there is for this objection. It is altogether the fault of the gas, which has a decidedly yellow tint; but our eyes are so accustomed to this coloured light, that electric light, which, like sunlight, contains all the colours of the spectrum, seems to us inferior, because it is on the contrary too rich, and objected to from the very excellency of its qualities.

Further advantages are that electric light has no smell, renders explosions impossible, diminishes the chances of conflagrations, enables us to obtain a light at long distances from the place of its production—an advantage which gas possesses at least to the same extent—and finally, if no direct but reflected light is required, it yields a splendid diffused light which can, from an economical point of view, successfully compete with gaslight.

And now let us consider the drawbacks. The first drawback, which is of a transitory nature, and is gradually disappearing in proportion as the apparatus are improved, arises from a want of constancy of the light, either with regard to its intensity or its colour.

With the apparatus described in this work, great constancy can be obtained, provided they are well constructed and well regulated. Serrin's regulators and others afford

all the necessary constancy. As regards candles, the changes of colour and of intensity are owing to the fact that these apparatus as has been mentioned in Chapter II., have sacrificed the quality of the light to the simplicity of the focus. The inconvenience arising from extinctions of short duration owing to the rupture of the arc, or of longer duration owing to accidental causes, disappears more and more in proportion as the staff entrusted with the manipulations becomes more experienced.

Certain electric lamps make a very tiresome noise, which excludes them from localities where silence is desirable. This particular noise may be very slight in candles and regulators which employ alternating currents, but it cannot be altogether avoided: it arises from the very nature of these currents, and can only be completely obliterated by the use of continuous currents: these currents find altogether more frequent applications for electric appliances than the former.

We have reserved for the last the most serious objections to the use of electric light.

The hydro-electric battery is not a practical or an economical apparatus for this application: the thermo-electric battery is still in the state of an experiment, so that electro-dynamic machines alone are available for producing the current; this necessitates, in most cases, the installation of a vapour or gas motor, and involves all the drawbacks inherent to these apparatus, such as stoker, engine-man, keeping in repair, etc.

This is the most serious drawback, and in fact the only serious one. It disappears, however, in certain factories where the motive force can be borrowed from the general transmission. In this case, electric lighting only presents

advantages. In other cases, what the gas companies do on a large scale has been done on a small scale; veritable electric workshops have been created, of which the Hippodrome in Paris offers a most remarkable instance. The magazines in the Louvre also have their electric workshop the same as the Salon (exhibition of pictures, like our Royal Academy) and the Avenue de l'Opéra. The solution of this question will undoubtedly be found in the creation of central electric workshops, distributing the electric current under similar conditions as the gas supply. The problem is a tempting one, and there is a future in store for it. While waiting for its complete solution, the advantages of electric light are so conspicuous that they altogether outweigh even this serious inconvenience. Steam-engines, gas-motors, hydraulic-motors, are now specially and exclusively employed for electric lighting; their number increases every day, which is the best proof we can adduce for this system of lighting.

There remain now the questions of expense, and of division of lights, which we are going to examine.

Expense of Installation and Working.—Nothing is more variable than the cost price of electric light; it may be ten times less expensive than gas or ten times more, as the case may be.

In a factory possessing a steam or hydraulic motor, a couple of horse-power for driving a Gramme's machine, which feeds either a Serrin's regulator or a series of incandescent lamps, can be spared, without involving any additional outlay.

The expense in this case is almost entirely confined to the first cost of the machine and the lamps, and to the combustion of the carbons. Under these conditions, electric

light, if well arranged, is in every way superior to gas. For the same reasons, it will be economical to use it in steamships, where there is always an abundance of steam, and where lighting with candles or oil is far more expensive. If, on the contrary, a steam-engine is set up purposely for driving a single Gramme's machine and feeding a single focus, the expense is quite out of proportion with the result, and the use of gas is clearly indicated.

By multiplying the number of centres to be supplied by one single motor engine, the disproportion gradually disappears, and if a powerful electric workshop is created, as is the case at the Louvre and the Hippodrome, electric light, from an economical point of view, is preferable to gas. If a battery is used—the Bunsen battery is up to the present the only one that has been used for lighting—the original outlay becomes enormous; it amounts, according to Becquerel, to two shillings and sixpence per hour for sixty elements, without counting labour. The battery is only used now in law courts, in national assemblies, and by some experimenters who from some reason or other cannot set up a steam or gas motor.

Gas-motors, which are employed in a certain measure, have rendered electric lighting economical, on account of the facility with which they can be set going and also stopped, and because they only consume when they are at work. Photography by electric light offers an instance.

If the gas-burner is a simple and convenient lighting apparatus, it cannot be denied, on the other hand, that its illuminating power is most inferior. By direct combustion of four cubic metres of gas, forty Carcel burners (640 candles) at the most can be obtained. By expending the same quan-

tity of gas in an Otto's motor, a force of four horse-power would be produced, which, transformed into electricity by a Gramme's machine and into light by a Serrin's regulator, would produce a luminous power of more than 300 Carcel burners (4800 candles), with 150 times less heat.

These figures show that, if gas-burners divide the light, this division is not effected without a certain loss nor without a considerable waste, which is as a rule not sufficiently taken into account.

According to Picou, whose estimates seem very accurate, a Serrin's lamp fed by a Gramme's machine can light 250 to 500 square metres of a workshop where delicate operations are carried on, or 500 to 1000 square metres of an ordinary mechanical workshop, or 2000 square metres of a dockyard.

The capital invested for this purpose would be £92, and the expense per hour, assuming 500 hours of lighting per year, would be—

	s.	*d.*
Carbon points	0	2
Coal for motor	0	1½
Repairs and labour	0	1
Interest on the capital	0	4½
Total	0	9

If the light is used every night—that is to say, 4000 hours per year—the expense only amounts to fivepence. With an hydraulic-motor, it is only sevenpence halfpenny for 500 hours, and fourpence for 4000 hours.

These figures, of course, only apply to one special case; they vary considerably for different systems of lighting.

The Division of Light.—Although electric lighting has made rapid strides within the last few years, improvements of a much more important nature must be in store for it, and these improvements are closely connected with a question

which is now the order of the day, and partly solved—the division of light.

It is evident that, if we succeed in creating small, economical centres, and, on the other hand, if electric workshops are established which deliver the current at the place where it is wanted, and in any quantity that may be required, as we can do with gas, all the drawbacks of electric lighting will at once disappear, and nothing but its advantages will remain.

No one would be considered over-sanguine now who predicted the realization of this industrial revolution. The manifold solutions which have been proposed show that it is possible, though difficult; the important results already obtained point to a satisfactory and complete solution in the nearest future. The improvements to be made are of two very different kinds. On the one hand, the division of the current must be kept in view, and, on the other, a perfect utilization of this current with properly organized centres. The present tendency is, as we can state to our great satisfaction, no longer to separate these two modes of research, and most of the inventors aim at constructing machines whose special qualities shall fulfil the requirements of the focus.

Thus, for instance, the Jablochkoff candle, which was formerly worked with Alliance machines, now employs almost exclusively Gramme's machines with alternating currents; and this affords a most remarkable instance of division, since one single machine can, according to its dimensions, supply from four to sixty candles, arranged in this latter case in twelve series of five candles each.

The alternating currents of Lontin's machine feed as many as twelve Mersanne's regulators; Siemens' machine

supplies twenty centres, arranged in two circuits only. Wilde's and Jamin's candles, Rapieff's and Gérard's lamps, give similar results from the point of view of division.

Continuous-current machines, also, allow of a division of light, either with the voltaic arc or by incandescence.

The Brush machine feeds forty regulators mounted for tension in the same circuit. This is the most remarkable result obtained as yet with arc lamps placed in one single circuit. All differential regulators, however, allow of this division, provided the current supplied by the machine is strong enough to overcome the resistance offered by the arc.

Even more remarkable results are obtained with incandescent light. A Gramme's machine (workshop type) can easily feed twelve Reynier's lamps in one single circuit, and twelve Werdermann's lamps in two circuits of six lamps each. And, to go further still, spirals of platinum-iridium, rendered incandescent and luminous by the passage of the current, allow of a division which is, so to speak, unlimited. It is true this latter process must at present be considered somewhat fastidious, and its application is of a very limited character; but the last word has not been said yet as regards this system, and the maximum utilization is far from having been obtained as yet.

The methods hitherto employed for the division of centres are defective in this one point—they do not realize, as a rule, an essential condition of a perfect system for division of light, and they are wanting in individual independence of the working centres from one another. The extinction of one Jablochkoff candle, for instance, causes the extinction of all the others placed in the same circuit; the extinction or the lighting of one centre influences all the

others, and either increases or diminishes their illuminating power.

Nor does the voltaic arc allow of a proper division of light; in fact, for the supply of a voltaic arc a certain minimum tension is required, and a volume of electricity depending on the size of the carbons, and if either of these two conditions is not fulfilled, the arc is completely extinguished. It seems, therefore, a well-established fact that the division of light into small centres is reserved, in spite of its higher price, for the incandescence of carbon or any other substance with analogous properties. A division such as to ensure for all the lamps supplied by the same electrical source an absolute independence, might easily be effected with the machines and principles known at present, provided the apparatus were placed under conditions altogether different from what they are now. By referring to what has been said on the mode of charging the inductors of dynamo-electric machines with continuous currents, it will be seen that the elements of electrical circulation, tension, and quantity vary considerably with the resistance of the circuit.

It naturally follows that any change in this resistance, brought about by the increase or decrease of the number of apparatus supplied, must immediately act on the electrical source, must cause a disturbance in the relations of the factors, and must influence all the other centres. The electrical source must, therefore, be placed under such conditions that these injurious reactions can no longer take place. This is possible by means of arrangements whose principle we can only indicate by comparison. Let us suppose a large reservoir full of water, which is to be distributed in a town by a large number of narrow tubes.

To obtain through each of these tubes a constant flow, whatever may be the requirements of all the others, the reservoir must be constructed under special conditions. First of all, it must have a large surface to prevent any sudden changes of level which would manifest themselves by changes of pressure and of flow in the conducting pipes. Secondly, the canal feeding the reservoir must be constructed in such a way that the quantity of water supplied is always equal to the quantity consumed, so as always to maintain the same level. And lastly, as a matter of course, in case all the conducting pipes should be opened at the same time, the quantity of the water consumed by the town must not be larger than that supplied by the basin, whose level would immediately be lowered. These are the principal conditions, and all of them can be realized.

For that purpose, the electrical source—the reservoir of our comparison—must always preserve the same tension of current in the external part of the circuit, in order that the shunted circuits—the conducting pipes—should always deliver the same quantity of current, whatever may be the number of circuits supplied. The work of the motive force must also be proportional to the expenditure, as in the case of our feeding canal.

To obtain this uniform tension, a machine or a series of electro-dynamic machines must be employed under such conditions that the resulting tension is constant; this result will be obtained by using separate inductors. Then the number of shunts established must not cause any variation of electrical flow in each circuit, which means that the generator must have a very feeble interior resistance, by using, for instance, several machines of the same kind, rotating with the same speed, and coupled for deriva-

tion as batteries are coupled for quantity. And, finally, the electrical flow of these machines must be regulated in proportion to the expenditure.

If all these conditions upon which we have only slightly touched are fulfilled, a real division of light with an absolute independence of centres will be realized in practice, because the intensity of the current supplied in each circuit will be constant.

The Brush System. A. The Brush Machine.[1]—The most

Fig. 96.—Portion of the armature ring, without coils.

Fig. 97.—Cross-sect of the armature rin

characteristic feature of the Brush machine lies in the for and construction of its armature, which consists of a cas iron ring, the cross-section of which is generally rectangul but in the direction of its circumference it is alternate wide and narrow, as shown in Fig. 96, which represen a portion of the armature ring. On reference to Fig. 9

[1] This description is taken from *Engineering* of January 21, January and February 4, 1881.

it will be seen that the ring is divided into as many sectors as there are bobbins to be wound, by a number of rectangular depressions or grooves; in these the coils of insulated copper wire are wound until the groove is filled up and the flat converging recesses become flush with the face of the intermediate thicker portions or pole-pieces by which they are separated from one another.

Fig. 97 is a cross-section of one side of the ring taken through one of these portions, and it will be observed that the intermediate thicker portions of the ring are grooved out by a series of deep concentric grooves, the object of which is partly to reduce the mass and lessen the weight of the revolving armature, partly for the purpose of ventilating the ring and thus carrying away a portion of the heat generated by the working of the machine, but chiefly for the localization and isolation of local currents generated by induction in the iron, and which would tend not only to reduce the efficiency of the machine by diminishing the magnetic capacity of the armature, but also to produce a heating of the ring, and therefore of the coils, whereby a portion of the current would be lost through their resistance being increased. For a similar reason, the periphery of the ring is grooved out deeply so as almost to sever the ring; by this means all cross currents are effectually cut off, and induction currents are compelled to flow in directions which are not detrimental to the efficiency of the machine. This again increases the area of radiating or cooling surface, and consequently helps to prevent the armature becoming overheated.

Fig. 98 is a sketch of the armature ring with all its coils wound; the two sides of each groove, and therefore of each coil of wire, are parallel to the centre line or radial

plane of the coil, and by the adoption of that form of bobbin, one of the practical difficulties in the winding of annular armatures of the ordinary form is avoided. All the

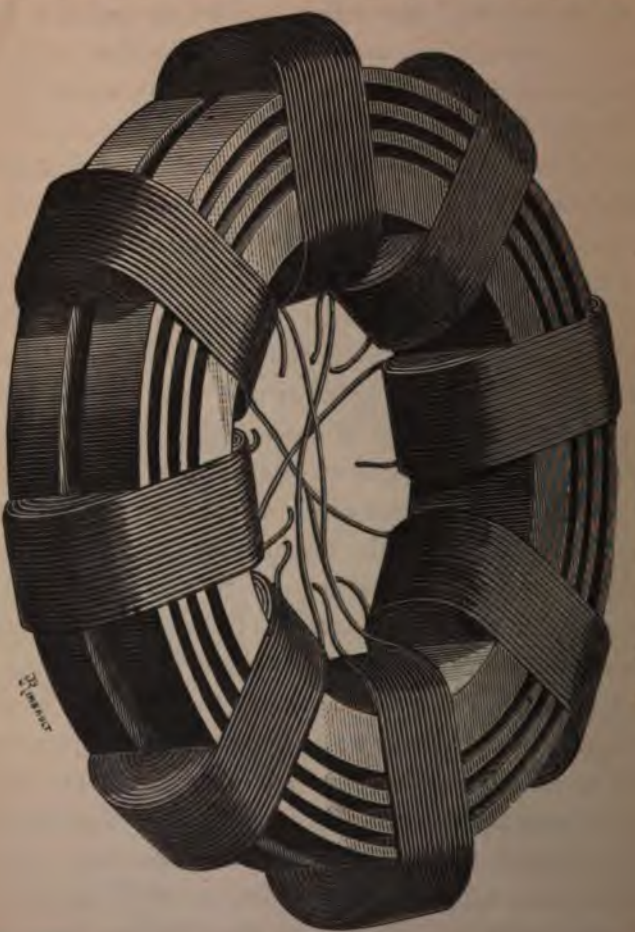


Fig. 98.—Armature ring, with all its coils wound.

coils are, like those in the Gramme machine, wound in the same direction.

Fig. 99 is a diagram, illustrative, not only of the distribution of the coils around the ring, but of the method by

which the connections are made. The inner end of each of the coils is connected by a wire to the inner end of the corresponding coil at the opposite end of the same diameter of the ring, and the outer ends of all the coils are brought through the shaft of the machine, and are connected to corresponding portions of the commutator, where the currents are collected by suitably placed copper plates or brushes. Referring to the diagram, it will be seen that the inner end A^1 of the coil 1 is connected to A^5, which is the inner end of the coil 5; A^2 is connected to A^6, A^3 to A^7, and so on round the ring; and the outer ends, B^1, B^2, B^3, etc., are

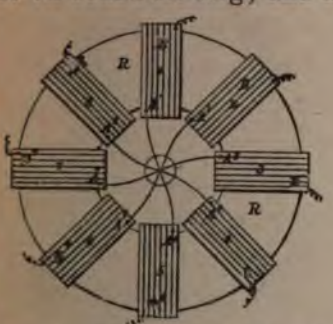


Fig. 99.—Distribution of coils and their connections.

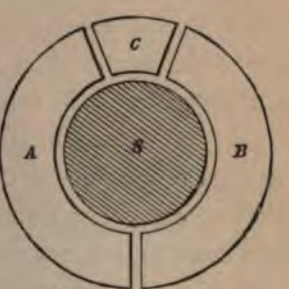


Fig. 100.—Section of a copper ring of the commutator.

all connected to the commutator by conducting wires insulated from one another. The two free ends of each pair of diametrically opposed coils are, after passing through the shaft of the machine, attached respectively to two diametrically opposite segments of the same commutator, which segments are insulated from one another and from any other pairs of coils. The commutator, which is attached to and rotates with the driving shaft of the machine, consists of a set of copper rings or flat cylinders, of which there are as many on the shaft as there are pairs of coils on the armature, and each of these cylinders consists of two segments insulated

from one another on one side of the shaft by a small air space about one-eighth of an inch wide, and on the other by a piece of copper separated from the segments by two smaller air spaces. The arrangement is shown in Fig. 100, in which A and B are the two segments connected respectively to corresponding coils on opposite sides of the armature, and attached by an insulating material to the shaft S; C is the copper insulating piece, the object of which is to separate either of the flat copper brushes or collectors, which press upon the periphery of the commutator, from either of the segments during the interval occupied by one pair of coils passing the vertical, or in other words, through the neutral portion of the magnetic field; this occurs twice in each revolution of the armature, and therefore of the commutator.

At the time when any pair of bobbins is in this way cut out of the general circuit, their own circuit is open, so that no current can circulate or be induced in them. By this most ingenious arrangement, each pair of coils has in succession in each revolution a period of rest equal to one quarter of a revolution, and has a current passing through it for only seventy-five per cent. of the time the machine is running; to it is, in a great measure, due the very small development of heat in the working of the Brush machine, and it presents also another important element of efficiency in the machine, namely, that each pair of bobbins as it passes the neutral portion of the magnetic field, and is therefore incapable of doing work and contributing electro-motive force to the general current, is itself cut out of the circuit, and thus two causes operating against the efficiency of the machine are eliminated. The first is one common to most armatures which have, like that in the Gramme machine, a

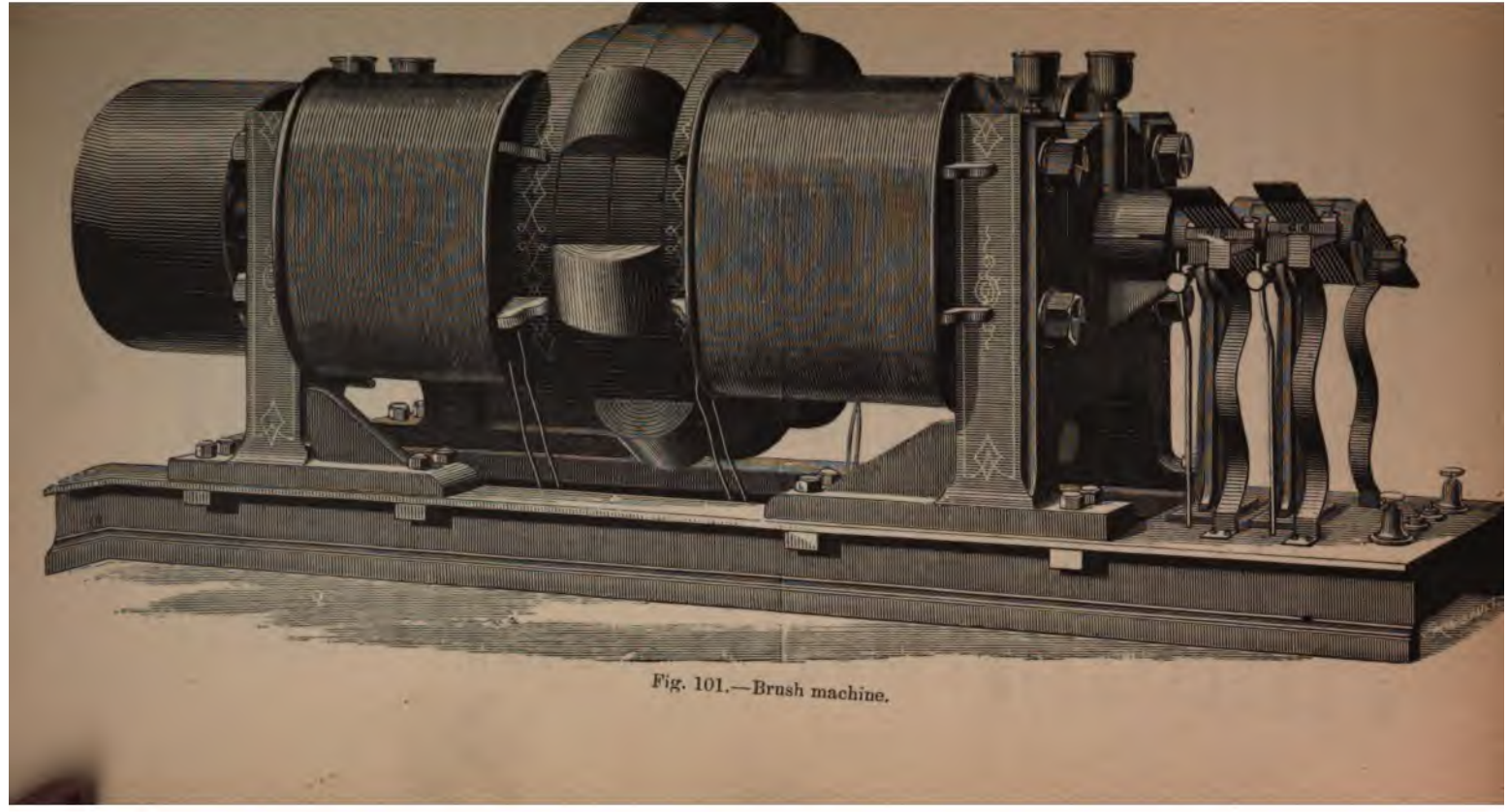


Fig. 101.—Brush machine.

permanently closed circuit, namely, that the currents generated in the bobbins have two routes open to them—the one through the conductors and commutators to the brushes, and the other through the idle bobbins, and thus, by a species of short-circuiting, robbing the external circuit of some of its current. The other cause of inefficiency which is avoided in the Brush machine is the reduction of its internal resistance by an amount equal to the resistance of two of the bobbins, for just as a certain amount of resistance is an item of efficiency when belonging to coils which are doing work and contributing electro-motive force to the general current, so does it become an element of inefficiency when belonging to coils which are idle, for in that case it diminishes the current supplied by the active coils, while at the same time contributing no current of its own in compensation. By the arrangement of commutator referred to above, Brush has, therefore, got rid of two considerable drawbacks to the efficiency of the machine.

What is, however, one of the important features of the Brush machine is the arrangement of the magnets by which the magnetic field is produced, and by which the armature coils are during their revolution almost continually passing through a very intense magnetic field. Upon reference to Fig. 101, it will be seen that the armature ring is closely embraced on each side by the large horizontal electro-magnets, whose poles are expanded so as to be presented to those of the armature coils on each side, leaving one pair of coils free from their direct influence, and this is the pair which is passing through the neutral region of the magnetic field. For the sake of illustration, the disposition of the magnets towards the armature and towards one another may be described as two horse-shoe electro-magnets placed opposite

one another in a horizontal position, their similar poles being presented towards one another, and having a small space between them in which rotates the armature ring. This space in the machines we are describing is, however, so nearly equal to the thickness of the armature, that there is hardly any clearance between them, the high-class workmanship of the apparatus allowing such close working with perfect safety.

Fig. 102 is a diagram illustrating the connection between the armature bobbins and the magnet coils at the time when the commutators are placing them in the same circuit.

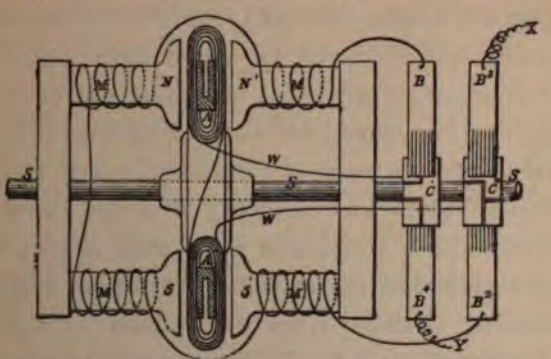


Fig. 102.—Connection between armature bobbins and magnet coils.

Referring to this diagram, M M and M M are the two magnets having their similar poles presented towards one another on opposite sides of the armature coils A A^1. Thus the coil A is under the influence of a magnetic field produced by the two north poles N N^1, while at the same time its corresponding bobbin A^1 is under the influence of the two south poles S S^1. A current is therefore induced in the pair of bobbins A A^1, which is transmitted by wires passing through the shaft S to the commutator C^1 C^2, whence it is collected by the brushes B^1 and B^2, and by them transmitted

to the magnet coils, which are all connected together in series, and at the same time, the other portions of the commutators (which are in connection with the other working armature bobbins) are in contact with the brushes B^3 and B^4, by which they are placed into the external circuit of the machine.

The commutators are a special feature of the Brush system; and the arrangement by which the position of the collecting brushes can be adjusted, so as to place them in contact with the commutators in any desired angular direction with respect to the position in the magnetic field occupied by the several bobbins to which the commutators are connected, is exceedingly simple and ingenious.

The commutating apparatus is represented on the extreme right of the general view of the machine (Fig. 101), and consists of two pairs of rings, of the form shown in Fig. 100, attached to and revolving with the main shaft, and, therefore, their position is fixed with respect to the revolving armature of the machine. On to the cylindrical circumferences of these rings are pressed two pairs of copper collecting brushes, which rub tangentially against the commutator rings, one pair pressing above and the other pair pressing below; a line forming the points of contact being a diameter of the ring. The copper "brushes," as they are called, are flat strips of elastic copper, about two inches wide, cut at the ends which press against the rings into eight tongues, so as somewhat to resemble a grainer's comb, and each comb or brush is wide enough to cover or be in contact with two armature rings, and in this way, although two of the coils are insulated twice in each revolution, the main circuit is never interrupted.

For the purpose of adjusting the brushes so as to make

contact with the commutators at the most effective angular position with respect to the magnetic field, they are mounted to the two opposite ends of two rocking levers, which are capable of oscillating on the driving shaft, and can be fixed in any desired position by means of a set-screw which clamps a stout wire issuing from the base of the machine. The currents are conveyed from the brushes by wide strips of thin sheet copper, shown in the general view, and in order to allow for the variable distances of the free ends of the brushes from the base of the machine, they are made undulating or wavy, doubling up as the distance is shortened, and stretching out when it is increased.

B. **The Brush Lamp.**— The great simplicity of the Brush lamp consists in the fact that the feed is actuated by gravity alone, while it is controlled solely by the influence of a magnetic field upon a bar of iron; the intensity of the field varies with the strength of the electric current passing through the lamp circuit. The general external appearance of the three forms is shown in Figs. 103, 104, and 105: the first representing the single-carbon, or eight-hour lamp; the second the double-carbon, or sixteen-hour lamp, with its glass globe removed; and the last is a sketch of a more ornate form of the double-carbon lamp, the controlling apparatus being enclosed in a nickel-plated case. In all these lamps, which are designed for general illumination, the lower carbons are fixed, and, as they burn away, the upper carbons follow them, so that the arc gradually descends; but for certain special installations, such as light-houses or for purposes of projection, a focus-keeping arrangement has to be applied.

Like most of the modern electric lamps, the upper carbon descends by its own weight until it touches the

lower carbon, and the circuit is thereby completed; the effect of this in the lamp we are describing is to cause a soft-iron plunger to be drawn to a more or less extent within a hollow coil, or sucking magnet, and, through the

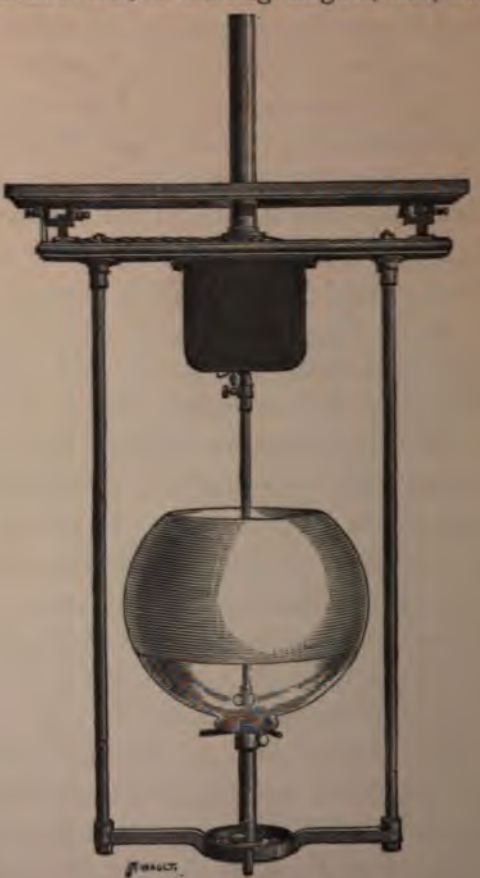


Fig. 103.—Single-carbon lamp.

intervention of a lever and an annular clutch surrounding the rod of the upper carbon like a washer, the upper carbon is lifted away from the lower, and the arc is established. As the carbons burn away, the arc has a tendency to become

longer and its resistance to increase, and this, by diminishing the strength of the current, diminishes the supporting power of the magnetic helix, allowing its plunger to descend,

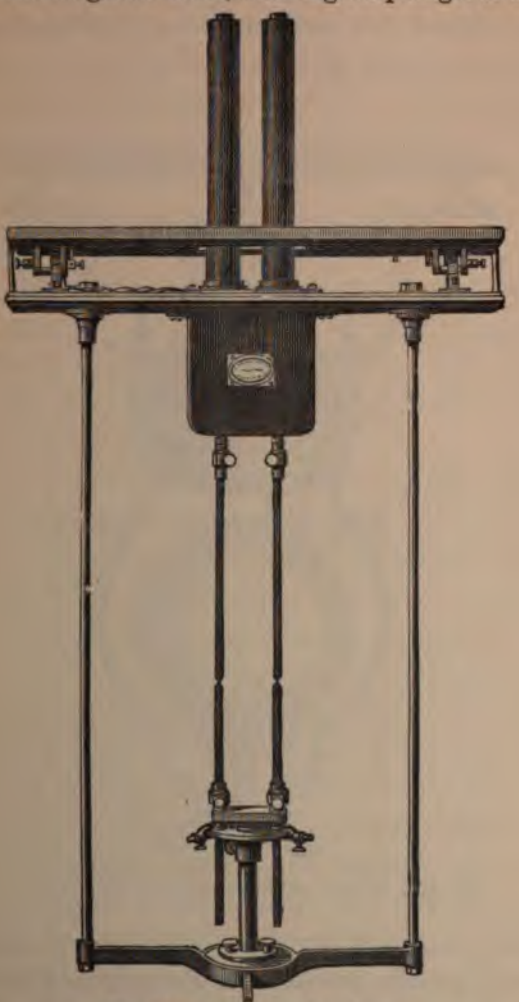


Fig. 104.—Double-carbon lamp.

and, in so doing, to lower the carbon and shorten the arc until the proper strength of the current is restored, when

the rising of the plunger once more holds the carbon in position. To ensure the individual independence of each lamp and a uniform light, each of the bobbins of the controlling magnet is wound with two distinct coils of wire, the first consisting of a number of turns of thick wire through which the current is transmitted to the arc, and

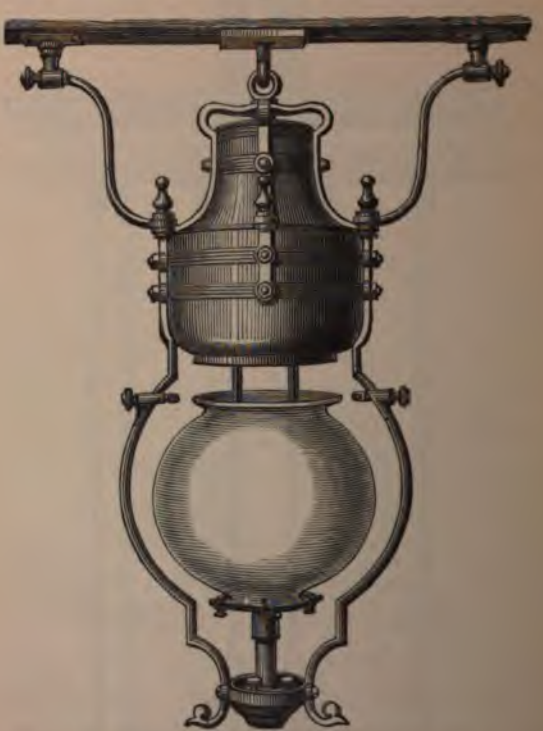


Fig. 105.—Double-carbon lamp, with plated case.

the second of a much larger number of convolutions of fine wire which forms a secondary or shunt circuit between the terminals of the lamp, the connections being made in such a way that the electric current shall pass through it in a direction opposite to that in the primary or thick-wire

circuit, forming a shunt circuit of high resistance through the lamp, which, being always closed, is independent of the arc. It will readily be understood that, as the current flows in opposite directions around the magnet, the influence of the fine-wire circuit will be to neutralize or weaken the attractive influence of the thicker helix; but the number of convolutions of the two coils, as well as their respective resistances, are so proportioned to one another, that the attractive influence of the primary helix (when the arc is of its normal length) shall overcome the influence of the secondary circuit. Owing to the greater resistance of the latter, not more than one per cent. of the main current is transmitted by the fine-wire helix, but its magnetic influence is rendered considerable by its greater number of convolutions.

From the above description it is clear that, since the electric current has two routes from one terminal of the lamp to the other—the one through the arc and the other independent of it—should the arc become too long, its resistance will increase, and a larger proportion of the current will be shunted through the fine-wire helix, while the strength in that of the thicker helix will diminish, the resultant magnetic influence on the plunger will be reduced, and the upper carbon will be brought closer to the lower; on the other hand, if the arc becomes shorter than its normal length, its resistance is reduced, more current flows through the primary helix, and less through the secondary, and the carbons are drawn further apart.

Fig. 106 is a diagrammatic sketch, showing the course of the primary circuit, and illustrating the general principle by which the arc is controlled; it also shows the short-circuiting contrivance by which any accident to one lamp

or irregularity of working cuts it out of the general circuit, and does so without exercising any influence upon the other lamps in the series. In this diagram, X and Y represent the two terminals of the lamp, which in most cases consist of hooks which, by being dropped over pins attached to the ceiling—and which are connected with the line circuit—place the lamp in circuit with the machine. The current, entering at X, is transmitted through the two hollow bobbins H H' in parallel circuit, the outcoming ends being joined together and connected to the upper carbon-holder N, and if the carbons are in contact, the current flows through them and by the vertical rods of the lamp to the terminal hook Y. The effect of this is to convert the solenoids H and H' into magnets, which, by drawing into themselves the two iron plungers N and S, lift one edge of the washer clutch W, which, by its oblique action, seizes the carbon rod (much in the same way as a tent-rope tightener grasps its cord) and lifts the upper carbon until its influence is balanced by that of the fine-wire helix, which, it must be remembered, surrounds the thicker coil.

The short-circuiting apparatus, shown to the left of the carbons K K' (Fig. 106), consists of an electro-magnet T, wound with a thick and fine wire coil similar to those of the regulating solenoids, but both wound in the same direction. When the thick-wire circuit of this magnet is complete, it forms a shunt of less resistance between the terminals, and therefore short-circuits the lamp, transmitting the current to the main circuit. Now, the fine wire wound upon this magnet is in circuit with the fine wire of the regulating solenoids; it follows, therefore, that if, through a failure of the arc, or through its becoming abnormally long, or through any considerable increase in its resistance,

a larger proportion of current be diverted through the fine-wire circuit, the attractive force of the electro-magnet T would be increased, and its armature A, which is attached to the pivoted lever B, would be attracted, the contact pieces M and M′ would thereby be brought together, and the terminals would be short-circuited through the thick coil M and the resistance spring R. By thus short-circuiting the terminals through a route altogether independent of either the fine or the thick wire solenoids, their magnetic action ceases, and either the upper carbon is dropped, or, if it is

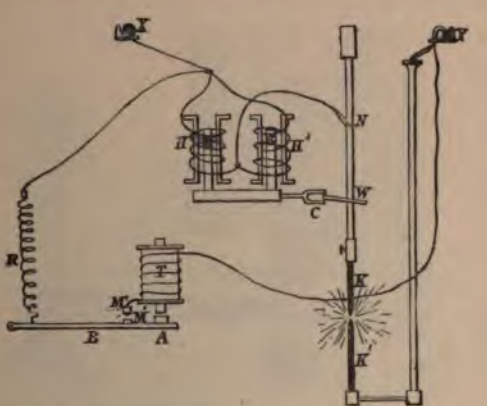


Fig. 106.—Diagram of the Brush lamp.

burned out or from any other cause the arc is not established, the contact pieces M and M′ are held firmly together by the attraction of the magnet T, and the current flows past the faulty lamp to the others in the series, its extinction calling attention to it, while the other lamps become proportionately brighter. The carbon pencils are a foot long, and are electro-plated with a thin covering of copper; they last about eight hours, during which time about nine and a half inches of the positive and about four

inches of the negative carbons are consumed. When, however, the lamps are required to burn for a longer period, double-carbon lamps are employed, fitted with two pairs of carbon-holders, as shown in Fig. 104, and each is controlled in the same way as in the single-carbon lamp, but the controlling apparatus is not duplicated. When the lamp is put into action, the arc is formed between one of the pairs of carbons, and when they have burnt out, the other pair automatically starts into action and continues to burn until

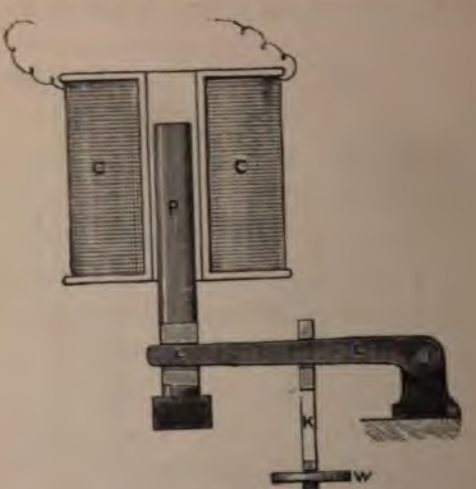


Fig. 107.—Two-wire solenoid of Brash's lamp.

it is in turn consumed; in this way the time of burning is doubled, and in order to extend the period of burning, it is only necessary to employ a lamp with a third pair of carbons, when it will be capable of illuminating for twenty-four hours, each additional pair of carbons extending the period of burning for another eight hours.

The change from the one pair of carbons to the new pair is effected by purely mechanical means, and by a con-

trivance as ingenious as it is simple. This little apparatus will be understood by reference to Figs. 107 and 108, which also more clearly illustrate the action of the washer clutch than the preceding figure. C C is the hollow solenoid, or "sucking magnet," which exercises a magnetic influence upon the soft-iron plunger P. The rising or falling of this plunger raises or lowers the little frame K (shown also in Fig. 108), by the intervention of the lever L. R^1 and R^2 are the carbon rods which pass vertically through the casing of the lamp, and W^1 and W^2 are the clutch washers which surround them. One side of each of these washers passes between a pair of jaws, forming part of the little frame K,

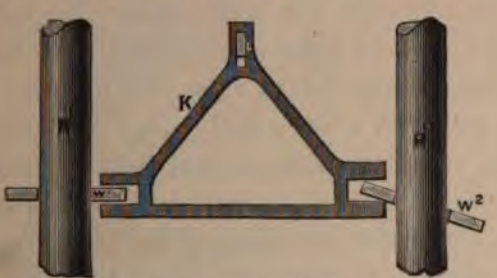


Fig. 108.—Arrangement for the change of carbons in the double lamp.

and when the latter is drawn upwards its action is first to tilt the washers and then to cause them to clutch the rod on diagonally opposite corners. By the very simple device of making one pair of jaws a little higher than the other, it takes its grip before the other begins to act, and consequently lifts its corresponding carbon higher than its neighbour; the consequence is that only one arc is established, viz. across the lesser distance, and in all consequent feeding and controlling the pair of carbons first started are alone affected, because, although both carbons are raised and lowered together, the lower end of the reserve carbon is

always higher than the other by the difference in the height of the two pairs of jaws on the frame K. A time arrives, however, when, owing to the shortening of the consuming carbons, they can no longer meet when the frame is dropped, and the current by which they are again separated can only be transmitted by the reserve carbons coming into contact, the circuit is thereby completed, the new carbons are separated, and the arc between them continues to be controlled by the magnet and clutch in the same way as the first arc was.

The Brush system is capable of establishing a greater number of large arc lights in a single circuit (as many as forty) than any other arc light system. It possesses also another very special advantage, and that is that a series of lights may be maintained at a great distance from the machine, and with a remarkably small loss; and this is of especial advantage where several lights have to be employed, because if there are as many long conductors as there are lamps, then the whole of the loss of current due to the resistance of the cables must be borne by each lamp, whereas if a number of lights can be included in a single circuit, the loss of current from the resistance of conducting cables is equally divided among all the lamps in the series. There are, of course, commercial advantages in burning a number of lights in a single circuit from one machine, for there must necessarily be an enormous increase in prime cost in the adoption of a number of dynamo-electric machines in the place of one, as well as in the multiplication of conducting cables, and the advantage in point of attendance and repairs is obviously in favour of the single-machine system.

Edison's system of electric lighting, which we have de-

scribed in the preceding pages, is a partial solution of the question of the division of electric light; and Maxim's system, which we will now describe, is another instance of the same.

Maxim's System.—Hiram Maxim's system is more complete than Edison's, in so far as it includes an automatic regulation effected by the machine itself according to the variation in the number of the circuits supplied.

The diagram Fig. 109 shows the mounting, and Fig.

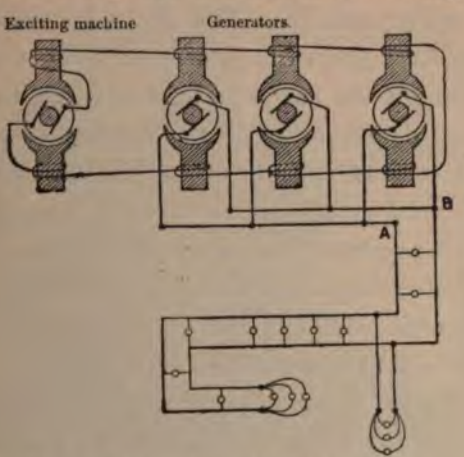


Fig. 109.—Mounting of Maxim's machine.

110 the whole of the so-called regulator. Maxim excites a certain number of dynamo-electric machines—three, for instance—by a fourth separate machine. The three generating machines are placed on shunts A B, and the lamps themselves are on shunts of the principal conductors. To understand the action of Maxim's regulator, let us suppress it for a moment, and displace the collecting brushes of the exciting machine by the hand, whilst both generating and exciting machines are in motion.

On referring to the working of Gramme's machine, it

will be seen that the current reaches its maximum when the brushes touch the collector in a vertical direction. When the brushes are placed in a horizontal direction, that is to say, when they touch the neutral point, there is no current at all. By moving, therefore, the brushes to an angle of about 90°, the current produced by the exciting machine will pass through all stages of intensity, from 0 to maximum. The magnetic fields of the generators will vary in intensity in the same proportion as the current produced by the exciting machine. The electro-motive force of the generators for a given constant speed being dependent on the intensity of the magnetic field in which the armature moves, any displacement of the brushes of the exciting machine must immediately act on the generators, and increase or diminish their intensity.

Maxim's regulator is an apparatus which automatically changes the bearing of the brushes, and renders the intensity of the magnetic field of the generators at each moment proportionate to the number of centres supplied.

It will now be easy to understand how the regulator (Fig. 110) acts. The upper part of the exciting machine carries two electro-magnets. We will only consider one of them for the present, the second one having an entirely distinct function. This electro-magnet is coiled with fine wire, the extremities of which are connected to the two terminals of the generator, the latter being in direct connection with the lamp wires. The armature of the electro-magnet is attached to a horizontal lever, whose path is limited by two abutment screws represented on the right; an antagonistic spring, regulated by a screw, balances the attractive force of the electro-magnet. The extremity of the lever of the armature is attached by a slightly elastic

metal wire to a horizontal lever which carries two small teeth, and receives a rocking motion by means of a small

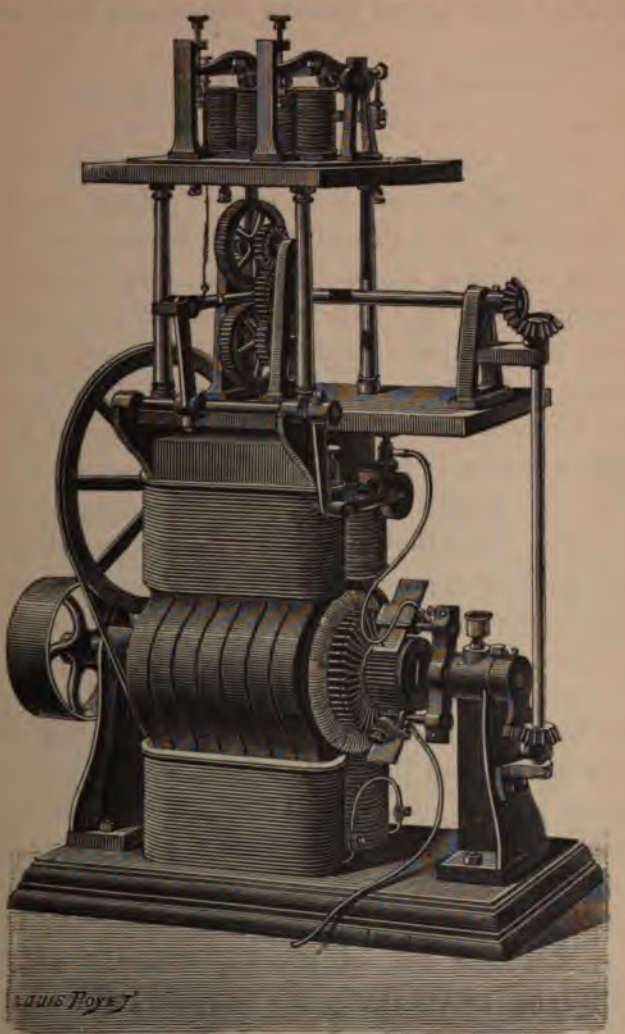


Fig. 110.—Exciting machine and regulator of Maxim's system.

connecting-rod and some transmission cords which connect

the rod (Fig. 110) to the shaft of the exciting machine and impart to it a comparatively slow rotatory motion. This horizontal lever moves between two wheels toothed like ratchet-wheels.

In the normal position of the armature and the lever attached to it, this lever moves freely in the space between the toothed wheels without acting upon either of them. Let us now suppose that two or three lamps are extinguished. The current thereby becomes too intense for the remaining lamps. The electro-magnet attracts its armature, the toothed lever is lowered, and the lower tooth works into the lower toothed wheel; the rocking motion imparts to this latter a rotation in a definite direction, so that for each turn of the small connecting-rod a slight rotatory motion is produced, which is transmitted to the brushes by a series of multiplying wheels, represented in Fig. 110. Under these conditions the brushes change their bearing; they approach the neutral point; the exciting current, and consequently the current produced by the generator, is weakened. These changes take place until the current recovers the requisite intensity for supplying the remaining lamps. The electro-magnet then releases the armature, and the toothed lever takes up again its normal position at an equal distance between the two toothed wheels. If any additional lamps are lit, the current is weakened, the armature acted on by the antagonistic spring is still further removed, the toothed lever this time acts on the upper toothed wheel, the multiplying wheels change the bearing of the brushes in an inverse sense and bring them near the maximum points, the intensity of the inductors and consequently the electro-motive force of the generator is increased.

The general adjustment of the whole system is thus in reality effected by the antagonistic spring. It suffices to slightly increase its tension to regulate the intensity of all the centres supplied by the machine. By diminishing the tension, the intensity of the lamps can be lowered to any degree, even to complete extinction.

Maxim's regulator is very sensitive, but unfortunately its action is also very slow. If too large a number of lamps were suddenly extinguished, the intensity would be too great in the remaining lamps, and some of them would undoubtedly break, being overheated by the sudden increase of intensity of the passing current.

In Maxim's system, the remedy, or rather a palliative, lies beside the evil. This palliative consists in a veritable safety-valve, which the inventor has added to his regulator, in the form of the second electro-magnet, which is to be seen in the upper part of Fig. 110. This second electro-magnet is similar to the first, and is placed in the same circuit as the first, which we had, in order to facilitate the explanation, supposed to be directly connected to the terminals of the generating machine. Its armature is also mounted on a similar lever, and is likewise regulated by a spring with a tension slightly superior to that of the regulator. If the current which simultaneously traverses the two electro-magnets is intense enough to attract the armature of the second electro-magnet, it will depress the lever. The lever will then directly join together the two brushes of the same exciting machine; it will form a shunt, and short-circuit the coil. Under these conditions the inductors of both the exciting and generating machines will no longer receive any current, the generator itself will supply no current, the intensity of the lamps will be

gradually diminished, a partial extinction of a few minutes will occur, but the lamps will be saved. Maxim must have thoroughly realized the fact that the regulator could not act effectually in all possible cases, to have endowed it with such a radical means of protection. It can, however, not be denied that, practically, the safety-valve is very rarely called upon to act, and that it is especially useful in cases of the sudden rupture of a main conductor or of some similar accident.

The results already obtained show that the division of light and of current power no longer presents any serious difficulties, and it is to be hoped that within a very short time electric lighting will have become one of the necessities of domestic life. The past here promises well for the future.

PART III.

TELEPHONES AND MICROPHONES.

A TELEPHONE is an instrument by means of which a sound, a melody, a noise, a song, or any utterance of the human voice can be transmitted to a distance.

These apparatus can, according to Preece, be divided into two large classes, according to the results obtained—

1. Musical telephones (tone telephones) are instruments for the transmission of melodious sounds.

2. Articulating telephones are those employed for the transmission of the human voice.

Microphones, as will be seen later on, naturally come under the same category as telephones, and require no special classification.

Tone telephones coming first in historical order, and being the simplest, we begin with them.

In a special chapter, we shall describe some telephonic apparatus, in which the transmitter, the receiver, and sometimes the line, are under such singular conditions that no definite place can be found for these instruments in a methodical classification.

CHAPTER I.

TONE TELEPHONES.

THE first mention of the principle of these telephones dates back as far as 1837, when an American, named Page, discovered that rapid changes of magnetization of iron bars produced what he called galvanic music. The sounds emitted by the bar depended on the number of changes produced in a second. Sixteen at least were required to produce a distinct sound.

These effects were carefully studied by a great number of physicists. De la Rive, of Geneva, in 1843, increased the effects of Page's vibrations—as these phenomena are sometimes called—by using wires of great length arranged in coils.

Later on, Sullivan discovered that the vibration of a wire composed of two metals produced an electric current which lasted as long as the vibration itself, but this discovery received no practical application, and would have fallen into oblivion without Bell's researches on the past history of his marvellous invention. In 1855, Léon Scott, of Martinville, invented an apparatus to which he gave the name of phonantograph, consisting of a stretched piece of skin vibrating under the influence of the voice, of singing, or any other sound. This instrument was designed for a

graphic representation of vibrations. This is the origin of the vibrating plate of the telephone.

Reiss' Tone Telephone.—In 1860, Reiss constructed an apparatus by means of which a melody produced in a certain place could be transmitted to a great distance.

This apparatus is a successful combination of Page's vibrations and of Scott's phonantograph; it is represented in Figs. 111 and 112. The former shows the apparatus for transmission, the latter that for reception. At the station where the tune is played, a large tube T, leading into the box K, receives the vibrations of the air produced by the instrument. The box collects and strengthens the sound. In the upper part, a membrane *m* is stretched, which vibrates in unison with the vibrations which it receives. The movements of the membrane are easily transformed into measured emissions and interruptions of an electric current.

Let us suppose a battery, one of whose poles is the ground, connected by the other electrode with the screw marked 2 in the figure; from thence a metallic conductor, formed of a thin copper plate *i*, and connected with a platinum disc *o*, conveys the current to a point opposite the lever *a b c*. Each time that the membrane *m* is raised, the point will touch the disc, and a current will be established; it is, on the contrary, interrupted when the membrane comes back into rest.

The upper part of the box K in our figure is cut off to show the details of the membrane and of the electrical connection which repeats the vibrations.

To transmit the electric current to a distance of 100, 200, or 500 kilometres, a line is required starting from the screw 1 (Fig. 111) and connected with the screw 3 (Fig. 112)

of the reception apparatus. This latter consists of an iron rod *d d*, surrounded by a spiral of insulated copper wire; one of the extremities of the wire is connected with the screw 3, and the other with the ground by means of the screw 4, in order to complete the circuit of the battery.

Rod *d d* is about the size of a knitting-needle; coil *g*, consisting of the copper spiral and the rod, stands on a hollow box B, made of very thin wood; a cover D fits over the coil. The whole of this arrangement is intended to

Fig. 111.—Transmission apparatus of Reiss' telephone. K, box for collecting the vibrations; *m*, indiarubber membrane closing the box (the upper part of the box has been cut off); *o*, platinum disc fastened to the membrane; *a b c*, movable lever touching the membrane; *t s*, key for manipulation; E E, electro-magnet receiver for correspondence; 2, 1, binding screws for connecting the wires with the battery and the line; T, mouthpiece.

strengthen the vibrations which produce the successive interruptions of the current across the rod *d d*. The principle is the same as in a piano, where the intensity of the notes is increased by the resonance of the case.

It is a remarkable fact that the vibrations of the rod *d d* are exactly synchronical with those of the membrane *m*, and consequently with those of the instrument playing the tune. Not only time is kept, but also tune; the two

factors which constitute melody, pitch and interval, are automatically reproduced, without any possible error.

To complete the description, we have to add that there is, in Fig. 111, a lever *t s*, and an electro-magnet E E, manipulator and receiver, as in an ordinary Morse, for establishing communication between the two correspondents.

In Fig. 112, too, the manipulating lever is to be seen; there is also a receiver, which is not represented in the diagram.

The form to be given to the box K is an important factor in the construction of this telephone; it has been found most advantageous to make the sides of curved

Fig. 112.—Receiving apparatus of Reiss' telephone. B, resonance box; D, cover of this box; *d d*, wire vibrating by the passage of the current; *q*, coil through which the current passes; *t' s'*, key for manipulation; 1, 2, 3, binding screws for connecting the wires with the battery and the line.

boards, to increase the effect on the membrane by successive reflections of sound. The power of the receiver has also been increased by introducing several iron rods into the coil; the sound, which was in the first instance muffling, has acquired a more pleasing timbre.

Reiss' apparatus was successively improved by Yeates, Van der Weyde, Cecil and Leonard Wray, but has always remained a purely musical apparatus.

Elisha Gray's Telephone.—The apparatus constructed by

Elisha Gray, of Chicago, in 1874, is nothing but a musical telephone, of the same kind as Reiss'; it was, however, more especially intended for multiple telegraphic transmissions, and the experiments made with it by Bell, Gray, Edison, and Varley, have led to the marvellous discovery of the articulating telephone. In Gray's telephone, the receiver has been provided with Helmholtz's resonance box.

The principle of the resonance box is that a volume of air contained in an open vessel emits a certain note when it is made to vibrate. The pitch of the note depends on the dimension of the vessel and that of the opening.

On bringing a resonance box close to the ear, when musical sounds are produced in the surrrounding air, it will be found that the one sound which is in unison with the fundamental note of the instrument is strengthened and distinctly heard from amongst all the others.

With a series of globes, graduated in such a manner that each corresponds to a special note, compound sounds have been analyzed and resolved into their elements. At the outset, the musician plays the tune by pressing the touches of a piano of sixteen notes; these touches are each connected with a distinct vibrating metallic strip, giving the note which corresponds to the touch.

Fig. 113 represents one of these metallic strips A vibrating between the coils B B. When it is on the right, for instance, the current no longer passes into the electro-magnet on the right, but passes into the one on the left, which attracts the strip; at the moment when the strip has arrived on the left, the current passes again into the electro-magnet on the right, and so on. The strip thus performs rapid oscillations, the number of which only depends on the length of the strip. Sixteen pieces, similar to those of Fig. 113, are

placed above the piano; the length of the strips of each of them is calculated so as to give all the notes of the two octaves. Each time that a note is struck, the electric

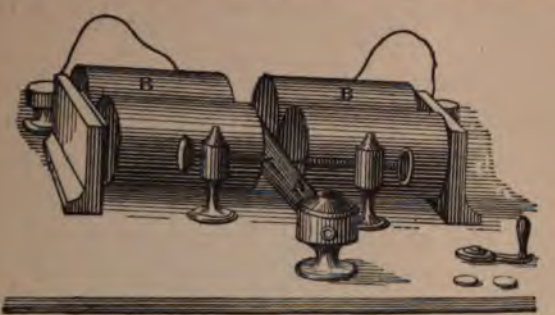


Fig. 113.—Vibrating transmission apparatus of Gray's musical telephone.

currents cause the corresponding metallic strip to vibrate. The tune is thus produced by the local electric current. As the strips vibrate at the outset, they open and close a

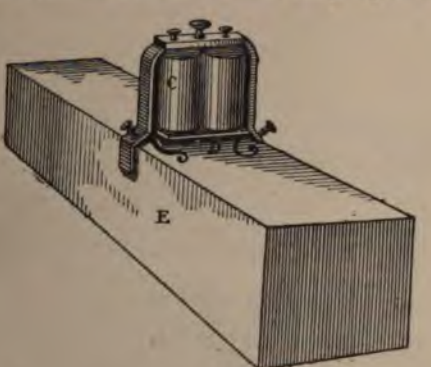


Fig. 114.—Resonance box of Gray's musical telephone (receiver).

line current, but all these interrupted currents reach the receiver, placed at a distance, by one single wire.

They must, therefore, on their arrival be separated by a new contrivance, the principle of which is based upon

Helmholtz's resonance box. The receiver is composed of a series of resonance boxes E (Fig. 114), with electro-magnets C, whose armature is formed in each case of a steel ribbon D, arranged so as to vibrate on the top of the resonance box E.

There are sixteen of these resonance boxes all connected with the line wire. Each of these partial receivers has, from its very arrangement, a sort of selective power; each appropriates and retains the vibration in unison with its resonance box, and is not influenced by the others. The electric waves produced at Philadelphia by the vibrations

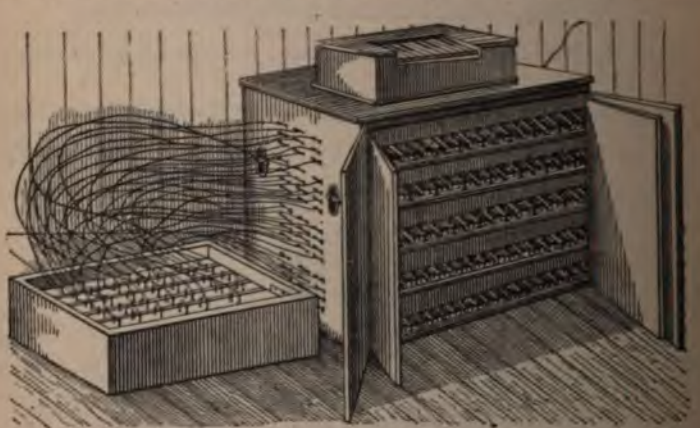


Fig. 115.—Gray's telephone-piano, played at Philadelphia.

of the metallic strip answering to the note C, for instance, will traverse all the receivers at New York, but they will only cause a vibration in the apparatus in unison with the note C.

Fig. 115 represents the piano of the musical telephone layed at Philadelphia.

All these apparatus, in spite of the great interest which hey must naturally present, were soon surpassed by the

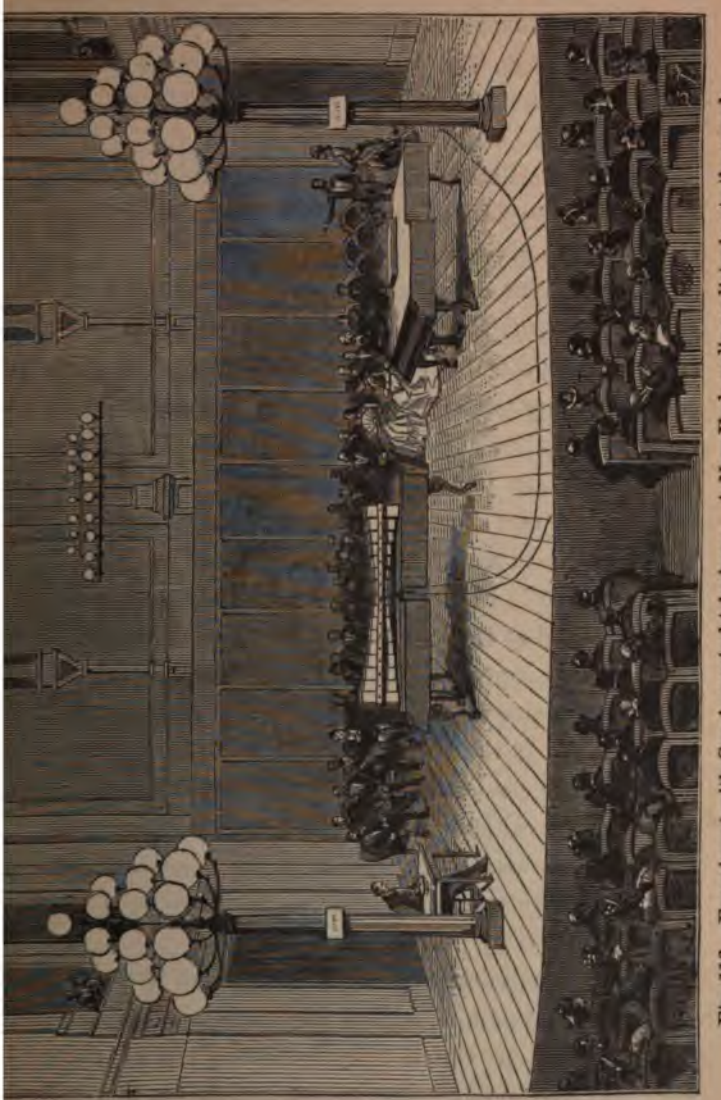


Fig. 116.—Experiment with Gray's musical telephone. A New York audience listening to the sounds produced at Philadelphia.

articulating telephone; but before we pass on to its description, we must first mention an apparatus with a very original receiver, and which, from the results it produces, must be classed among the musical telephones. We are speaking of the singing condenser.

Singing Condenser.—The principle of this apparatus was discovered by Varley, as early as 1870, but Pollard and Garnier have given it its practical form.

The receiver consists of a condenser, formed of thirty sheets of paper, nine centimetres by thirteen, separated from one another by twenty-eight sheets of tinfoil, nine centimetres by twelve, joined in such a manner as to form the two armatures of the condenser. For this purpose, the even sheets are joined together at one end of the paper pile, and the odd sheets at the other end.

This pile is spread on a piece of stiff cardboard, after having carefully tied it with a strip of paper; the pieces of tinfoil, united at the two ends of the condenser, are pressed between two copper bands carrying binding screws for the wires of the circuit, and thus a veritable singing apparatus is obtained. If the sheets are pressed by a heavy weight placed on the condenser, its action is not arrested, only the sounds are weakened, and become more harmonious. The theory of an attracting motion of the sheets, which had been originally started to explain these effects, is rendered rather doubtful by this latter experiment.

The transmission apparatus consists of a sort of telephone without handle, with a very thin vibrating tin plate, in the centre of which a cylindrical piece of carbon is soldered; and against this carbon presses another cylinder of the same material, which is fixed to a jointed wooden cross-bar, fastened on one side to the lower edge of the

telephone box, and on the other to the opposite edge of the box by means of a regulating screw. A curved spring (a piece of clock-spring) placed across this piece gives it a certain elasticity which is necessary for the working of the apparatus. The tin plate is connected with one of the poles of a battery, and the lower carbon is connected with the primary helix of an induction coil, which has been connected with the second pole of the battery. Finally, the two ends of the secondary helix of the induction coil are directly connected with the two armatures of the condenser.

The secondary helix is formed of twenty layers of wire, No. 32, or better still, No. 42, covered with silk; and the primary helix is formed of four layers of wire, No. 16. The circumference of the coil must not exceed seven centimetres, and the diameter of the core of fine iron wire must be about one centimetre.

To obtain a song on the condenser, the two carbons of the transmitter must not touch under normal conditions, but must be sufficiently near one another to effect contact by the vibrations of the plate produced by the singing. This adjustment is easily obtained by repeated trials, and by sounding the same note until the condenser resounds. If three successive notes are clearly reproduced, the apparatus may be considered satisfactorily adjusted, and is set in action by simply singing into the mouthpiece. To make sure of a good result, the plate of the apparatus must be heard to vibrate like a reed-flute. Instead of the carbons, platinum contacts may be used.

Janssens has constructed a singing condenser, in which the speaker has the form of a Bell's telephone; the coil is placed in the handle, which renders the apparatus very

portative and convenient. All musical telephones are nowadays only considered as objects of curiosity, or apparatus for physical experiments; they are, however, worthy of mention as having in some way prepared the way for the invention of articulating telephones.

CHAPTER II.

ARTICULATING TELEPHONES, OR SPEAKING TELEPHONES.

It is the admirable apparatus of Professor Graham Bell which first solved, by a method of marvellous simplicity, the problem of electric transmission of the spoken word to a distance. Bell's telephone, patented by its inventor on the 14th of February, 1876, made its first appearance at the Philadelphia Exhibition, and Sir William Thomson, at a time when this invention met with almost universal incredulity, designated it by the name of "marvel of marvels." Before analyzing the researches which led Bell to his discovery, we must cast a rapid glance at the previous researches on this subject, and the state of the question when it was taken up by the successful inventor.

String Telephone.—Leaving aside acoustic tubes, which, so to speak, only constitute a canalization of the human voice through a tube, the first telephone deserving of this name was the string telephone, the invention of which dates back more than two centuries.

As will be seen in the sequel, the problem of telephony resolves itself into this: To produce a synchronical vibration of two objects placed at a certain distance from one another.

The simplest method is to take two cylindrical tubes of metal or cardboard, to close one of the extremities of each

tube with a membrane of paper, parchment, or thin cardboard, and to connect the two vibrating sheets thus formed by a string fixed in the centre by a knot.

When the string which joins the two parts is well stretched, and not too long, and one of the tubes is held to the ear whilst another person is speaking very close to the mouthpiece of the other tube, all the words are transmitted by the string to the membrane of the receiver, and a conversation can be carried on with a very low voice.

Here we have a mechanical transmission of vibrations and a synchronical movement of the two membranes.

Speech can thus be transmitted as far as 200 metres. By using diaphragms of very thin iron, and insulating the wire on glass supports, Huntley, who made the experiment, was heard at a distance of 2450 feet, in spite of the zigzags of the line. String telephones have for a long time remained in oblivion, and have only lately been taken up again.

It was Charles Bourseul who, in 1854, first gave vent to the idea of transmitting sound to a distance by electricity, and Count du Moncel declares, in his work (*The Telephone, the Microphone, and the Phonograph*, 2nd edit., 1882. London: Kegan Paul, Trench, and Co.), that this idea was regarded as a fantastic dream. All the researches made from that time till 1876, when Bell's telephone came out at the Philadelphia Exhibition, had for their object the construction of musical telephones. Helmholtz's researches on the synthesis of sounds opened the way for articulating telephones.

Nobody could have been more fitted than Graham Bell to undertake these investigations and lead them to a successful issue, for the invention of the telephone is the result of a long series of researches which Graham Bell had made

in conjunction with his father, Alexander Melville Bell, of Edinburgh. He commenced with the study of the sound of vowels, made experiments analogous to those of Helmholtz on the artificial reproduction of vowels by means of electrical tuning-forks, constructed an electrical harmonium, a Morse's sounder, and devoted himself entirely to the study of electrical reproduction of speech. The whole of Graham Bell's investigations on the telephone are contained in a paper which the author read before the Society of Telegraphic Engineers, in London, on the 31st of October, 1877. It was reproduced in *La Nature* of April, 1878.

After having, with remarkable impartiality, given an account of the whole of the anterior researches made in the

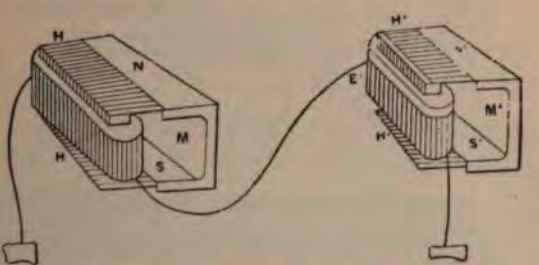


Fig. 117.—First form of Bell's articulating telephone.

same direction by his predecessors, and after some general remarks on undulating currents, which would be out of place here, the inventor thus describes the first form of telephone which he had constructed—

"The apparatus represented in Fig. 117 was my first form of articulating telephone. In this figure, a harp with steel chords is attached to the poles of a permanent magnet N S. As soon as any one of these chords is set in vibration, an undulating current is produced in the coils of the electro-magnet; the corresponding electro-magnet E', attracts the

chords of the harp H′, with a variable force, and sets in vibration the one chord which is in unison with the chord vibrating at the other end of the circuit. This is not all; the amplitude of vibration in one of the chords determines the amplitude of vibration in the other, for the intensity of the induced current is determined by the amplitude of the inducing vibration, and the amplitude of vibration at the end of reception depends on the intensity of the attracting impulses. When we sing into a piano, certain chords of the

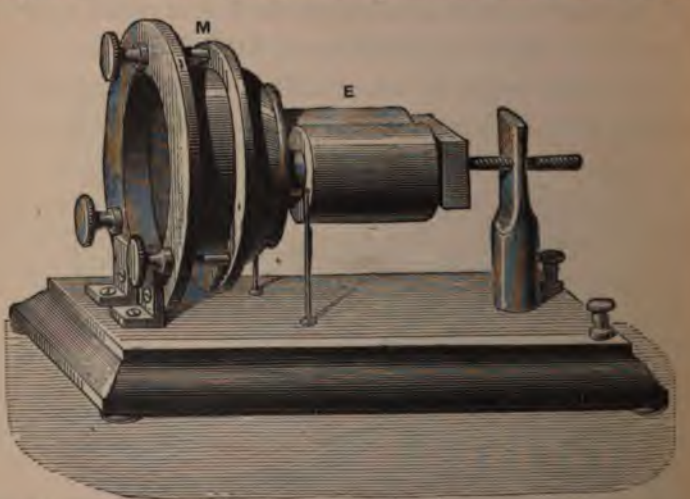


Fig. 118.—Bell's speaking telegraph at the Philadelphia Exhibition (speaker).

instrument are thrown into sympathetic vibrations by the action of the voice, and, for different degrees of amplitude, an approximate sound of the vowel pronounced issues from the piano. Theory shows that if the piano had a much more considerable number of octave chords, the sounds of vowels would be reproduced to perfection. My idea of the action of the apparatus which is indicated in Fig. 117 was the following:—To emit a sound in the neighbourhood of

the harp H, and certain chords would be set in vibration with different amplitudes. At the other extremity of the circuit, the corresponding chords of the harp H′ would vibrate with their proper relations of force, and the timbre of the sound would be reproduced. The expense of construction of a similar apparatus prevented me from entering upon this line of research."

After having reviewed the first apparatus which he constructed for reproducing speech at a distance, Bell describes the apparatus exhibited at Philadelphia, in 1876.

In this apparatus, the speaker (Fig. 118) was formed by an electro-magnet E and a vibrating membrane M, on which Bell places, as a sort of armature, watch-springs of the size of a thumb-nail.

The receiver (Fig. 119) was formed of a tubular Nicklès' electro-magnet F, on which was fixed with a screw a slight armature of sheet iron, of the thickness of a strong piece of paper, which acted as a vibrator; a small bridge placed on the socket acted as a sounding-box.

It must, however, be remarked that the apparatus thus constituted was not an electro-magnetic telephone, for a battery of several elements was placed in the connecting circuit of the two apparatus. The sound was only transmitted by a sort of induction produced by the armature on the current of the battery traversing the electro-magnet E of the speaker. This apparatus enabled Bell and his friend Watson to obtain telephonic transmissions, which put them on the right way.

"I remember," said Mr. Bell, in his lecture, "an experiment made at that time with the telephone, which gave me great pleasure. One of the two apparatus was placed in one of the lecture-rooms of Boston University, the other in

the basement of a neighbouring house. One of my pupils was observing this latter apparatus whilst I held the former. After pronouncing the words, 'Do you understand what I am saying?' what was my joy when I heard myself this answer through the instrument, 'Yes, I understand you perfectly.' The articulation of the words was certainly not perfect yet, and it required the greatest attention on my part to distinguish the words of this answer; yet the articulation of the words was a fact, and I was led

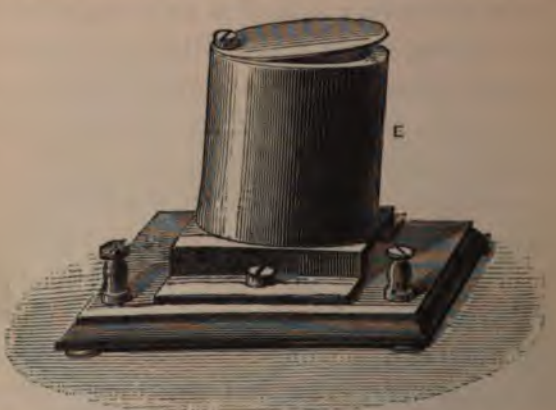


Fig. 119.—Receiver of Bell's telephone at the Philadelphia Exhibition.

to believe that their want of clearness was simply attributable to the imperfection of the instrument."

The great defect of the receiver was that it could not serve as transmitting apparatus; two apparatus were, therefore required at each station. After a long series of experiments, Bell suppressed the battery, and used a permanent magnet as magnetic core.

This is the first magnetic telephone, represented in Fig. 120 in its original form, as brought before the Essex Institute, at Salem, Massachusetts, on the 12th of February.

1877. On that occasion he reproduced, before an audience of 600 persons, a speech delivered at Boston into a perfectly identical apparatus.

Fig. 121 (p. 314) shows the lecture-room at Salem at the time when Graham Bell delivered his lecture; the telephone wires ended at Boston, twenty-two kilometres (fourteen miles) distant, where one of the assistants distinctly heard the words pronounced by Mr. Bell (Fig. 122, p. 315), and a few minutes after, the enthusiastic applause of the Salem audience was distinctly heard at Boston. During this memorable experiment, Bell communicated with Boston through an ordinary Morse telegraph, worked on the plat-

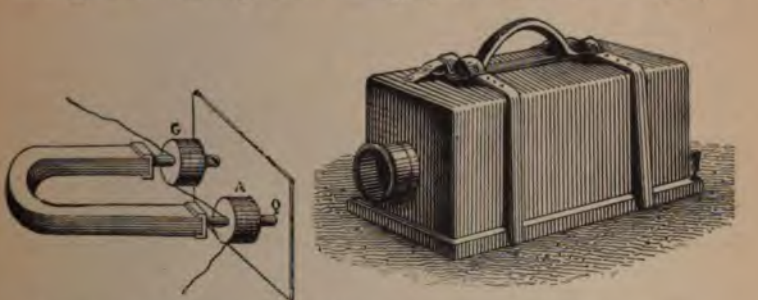


Fig. 120.—Bell's telephone, model with identical speaker and receiver. Tested at Salem, on the 12th of February, 1877.

form where Bell was standing; this telegraph fixed the moment of the beginning of the experiment.

There is only one more step to Bell's telephone such as we know it in its practical and portative form.

Preece was the first to show the possibility of using magnets of very small dimensions, and also to determine the most convenient form which was to be given to the mouthpiece.

Before describing the different telephones from the point of view of their principle and their construction, we must

Fig. 121.—Lecture on the telephone, given at Salem (U.S.A.), on the 12th of February, 1877, by A. Graham Bell.

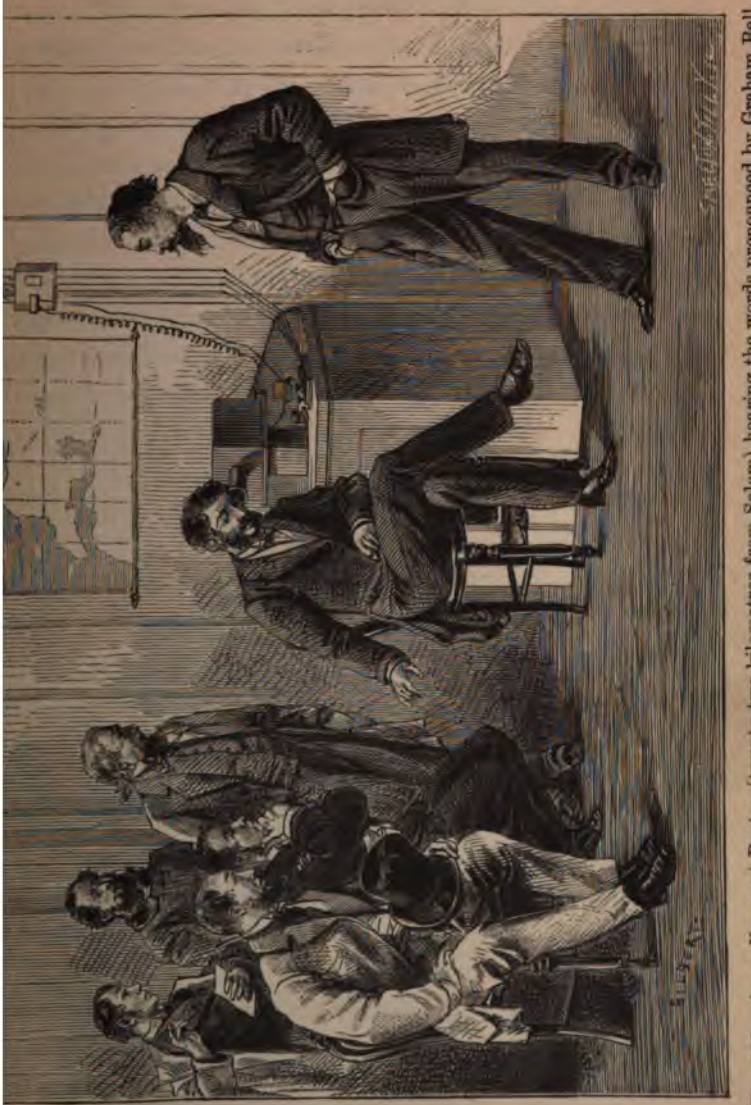


Fig. 122.—An audience at Boston (twenty-two kilometres from Salem) hearing the words pronounced by Graham Bell.

say a few words on the part which Elisha Gray took in the invention of the telephone; and for this we can have no better authority than Du Moncel, who has closely followed the numerous researches made on this subject. By a remarkable coincidence, of which we have already had an instance with regard to the principle of dynamo-electric machines, Bell's and Gray's patents were lodged on the same day, the 14th of February, 1876, and both called attention to the importance and necessity of undulating currents for the electrical transmission of speech or of combined sounds.

In the apparatus patented by Gray, the undulating currents required for telephonic transmission were obtained

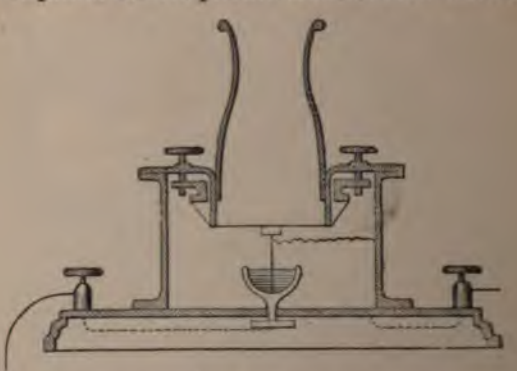


Fig. 123.—First model of Bell's speaker (with a liquid).

by varying the electrical resistance of the circuit, and consequently the intensity of the current in this circuit.

Bell's and Gray's speakers are identical as regards principle, and similar as regards construction.

We reproduce (Fig. 123) the diagram of Bell's speaker, in which a platinum wire attached to a stretched membrane completed the voltaic circuit by being immersed in water. The vibrations of the membrane modified the resistance of the speaker, and consequently the intensity of the current.

This is the principle of the battery telephone, and Edison's carbon telephone and the microphone are nothing but improvements upon this latter apparatus.

In reality, the problem had been followed up and solved by both the inventors, but by very different methods; whilst Gray has persisted in constructing telephones with a battery and a liquid speaker, Bell has first constructed a magnetic telephone without battery. He is entitled to be called the inventor of the telephone, and nobody now contests his claim, for the lawsuit between Gray and Bell has been amicably arranged. Bell's Telephone Company in America has the exclusive patent right, not only of Bell's telephone, but also of Gray's, and of the more recent apparatus of Edison and Phelps. Finally, it has to be recorded that Yeates, of Dublin, as early as 1865, in attempting to improve Reiss' telephone, constructed a speaker similar to Gray's, by introducing a drop of water between the platinum contacts of Reiss' apparatus. The musical telephone might have become an articulating telephone under these conditions, but this result was not obtained, partly on account of the imperfection of the instrument, and partly because Yeates had no such result in view.

Classification of Telephones.—The number of telephones of different systems increases every day, but, notwithstanding the infinite variety of these apparatus, they can be divided into two quite distinct classes—

1. Telephones without battery, or magnetic telephones.
2. Telephones with batteries.

This latter class comprises carbon telephones and micro phones.

Magnetic telephones being the simplest and least numerous, we will commence our review of the principal telephonic apparatus with them.

Magnetic Telephones.

Every telephone, whatever may be its construction, consists of two quite distinct parts—

1. The speaker, which transforms the spoken words into undulating currents, which are sent along the line.

2. The receiver, which, as the name implies, receives the undulating currents, and transforms them again into sonorous vibrations.

The first characteristic property of magnetic telephones is the absolute identity of speaker and receiver, both of which can easily act either part. A complete magnetic system, therefore, consists of two apparatus only, while battery telephones employ four—two for each station.

The first and simplest of all magnetic telephones is Bell's, whose successive modifications have already been described, in the inventor's own words, at the beginning of this chapter.

Bell's Telephone.—The latest form given to this instrument by its inventor consists of a small wooden or ebonite box, provided with a handle F F′ (Fig. 124), which contains the magnet A placed opposite the vibrating plate M, and serves at the same time for holding the instrument in the hand. By means of a screw placed at the extremity of the handle, the magnet A is brought near the vibrating plate or removed from it, and this constitutes the adjustment of the instrument. At the extremity of the magnetic bar is a bobbin B, whose thickness of wires and number of spirals must be proportionate to the length of the line, in order to obtain the best effects. The vibrating plate, which has only a diameter of five centimetres in its free part and a thickness of $\frac{1}{30}$ to $\frac{2}{30}$ of a millimetre, is of sheet iron, and

coated with varnish or tinfoil to prevent its oxidation. The mouthpiece E screws on to the box either by independent screws, as in Fig. 124, or by a screw-channel, and the vibrating plate is squeezed between it and the box and thus kept in position.

The working of the apparatus is well known: we recall it in a few words. On speaking before the mouthpiece of a telephone, the plate vibrates; by its movements it modifies the division of magnetism in the magnetic bar, and gives rise to induced currents in the bobbin placed at its extremity. The telephone is, therefore, a real generator of electricity—a generator of marvellous sensibility, which modulates the intensity of the currents it produces and

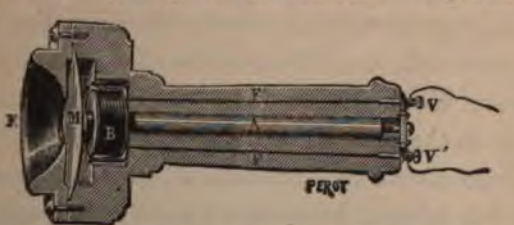


Fig. 124.—Bell's telephone (ordinary hand model).

makes them follow all the varying and complicated undulations which characterize articulate sounds.

These undulating currents, thus developed in one telephone by the vibrations of the plate, are conveyed by two conducting wires to a second telephone, which transforms them again into sonorous vibrations. For a first explanation—inaccurate inasmuch as it is incomplete—it may be assumed that the undulating currents of alternately inverse sense reach the receiving telephone, increase the magnetism of the bar if they traverse the bobbins in a sense favourable for magnetization, and diminish it if they are of inverse sense; the plate obeys these changes

of magnetization, approaches the coil when the magnetic force increases, withdraws from it by its own elasticity when the force diminishes, and by this undulating action, like the exciting currents, vibrates in unison with the plate of the transmitting telephone, although with imperceptibly smaller displacements.

The sounds emitted by the receiving telephone are not perceptibly weakened by the interpolation of several telephones in the circuit. As many as ten or twelve telephones have been placed in the same circuit, and the words pronounced at the other extremity of the line have been distinctly heard by ten or twelve persons at the same time.

We only quote this experiment to show the extreme sensitiveness of the marvellous instrument invented by Professor Bell. We shall have many opportunities of referring to it again in the subsequent treatment of our subject.

The successive transformations which take place in the inappreciable interval between the moment when the sound issues from the mouth of the speaker, and the moment when it strikes the ear of the listener, are most interesting. They are seven in number—

1. The vibration of the air sets the plate of the speaker in motion.

2. This motion changes the magnetic division of the magnetic bar.

3. The change in the magnetic division develops induced currents in the bobbin of the speaker.

4. These induced currents traverse the line and the bobbin of the receiver.

5. These currents produce changes in the magnetic bar of the receiver.

6. These changes of magnetism act on the plate and cause it to vibrate.

7. The vibrations of the plate are communicated to the air, and strike the tympanum of the listener's ear.

This is one of the most beautiful illustrations of the equilibrium and the unity of natural forces—an equilibrium which is so well established, that no change, however slight, can ensue in one of them without immediately producing corresponding changes in all the others. The effort developed by the emission of a sonorous vibration is very slight, and yet the telephone reproduces its echo at a distance of 300 or 400 kilometres (200 to 250 miles)!

Many have been the imitations of Bell's telephone, and most of them are modifications without any practical value and without any importance. We cannot examine all these apparatus, already more than a hundred in number; we must confine ourselves to the description of those modifications which have given in practice superior results to the inventor's apparatus, and have enabled the listener to hear the words more distinctly on placing himself, in some cases, at a certain distance from the receiver. We must, however, not lose sight of the fact that the magnetic telephones mentioned below in no way constitute a new discovery or invention, but simply an improvement of more or less practical value.

Gower's Telephone.—This is an important improvement of Bell's telephone, for it renders the words pronounced by the receiver audible in every part of a room. It must, however, be remembered that Bell had partly obtained this result in his memorable experiment at Salem. In Gower's apparatus (Fig. 125), the magnet N O S is very powerful, notwithstanding its small dimensions. The two

poles support a small oblong piece of iron, on which the bobbin is fixed. The whole is enclosed in a flat brass case, whose cover carries the vibrating plate M. The thickness of this membrane is slightly greater than that of the preceding apparatus; it is fastened to the cover by a ring and some screws placed in the circumference of the ring.

Gower employs, instead of the ordinary telephonic

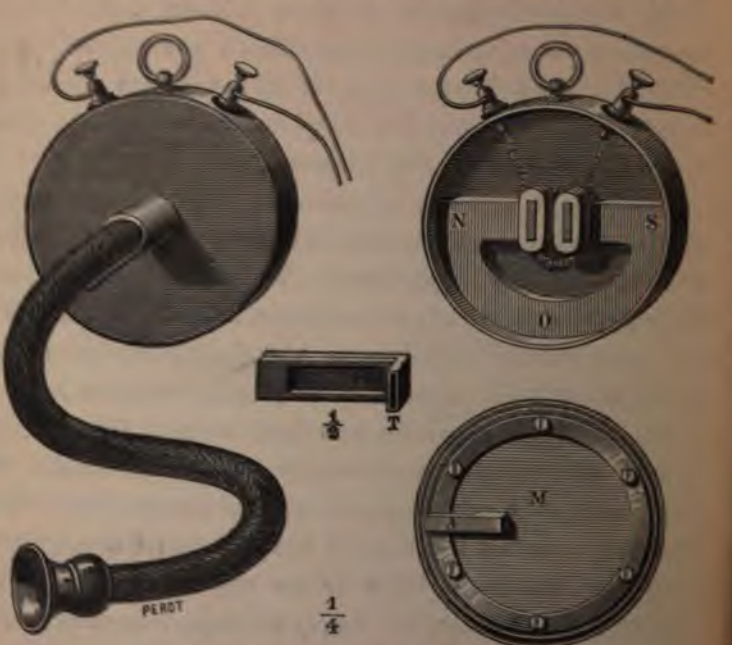


Fig. 125.—Gower's telephone.

mouthpiece, flexible acoustic tubes like those of a speaking-trumpet.

To sound the warning, Gower employs a special arrangement, represented separately in half natural size. It consists of a tube bent at right angles, with one end T opening on to the vibrating plate, and the other end into the case;

it contains a vibrating reed L. By blowing into the acoustic tube, the reed vibrates and communicates its vibration to the plate of the telephone much more effectually than could be done by shouting into the mouthpiece. These intense vibrations produce powerful induced currents, which give rise in the receiver to corresponding vibrations, and thus create a considerable noise.

The peculiar timbre of the sound renders it easily perceptible in the midst of a certain dull noise.

By adding a large resonant ear-trumpet to the apparatus, the word can be heard at a distance.

The addition on the membrane of the tube A in no way disturbs the clearness of transmission.

Ader's Telephone.—We find again in this instrument the circular magnet and the double bobbin of Gower's telephone, but it differs from the latter by having a circular armature of soft iron placed in the body of the mouthpiece in front of the diaphragm. The armature produces an overcharge in the magnet; this overcharge might be obtained by increasing the mass of the diaphragm, but the result would then be produced at the expense of its vibrating capacity. Ader's armature fulfils the same purpose while not interfering with the lightness of the membrane; Gower's telephone, however, shows that the mass of the vibrating plate has no injurious effect.

Although Ader's telephone is more especially constructed to act as receiver with battery speakers (of which more hereafter), it must nevertheless be counted amongst the magnetic telephones, because two similar conjugate apparatus can transmit speech like two Bell's telephones.

Most of the magnetic telephones which will be described in the following pages act also as receivers of battery tele-

phones; by examining them in their proper place we shall only have to quote them on studying each system of speaker.

Crown Telephone.—In this instrument, which serves more especially as receiver for Edison's carbon telephones, the straight bar of Bell's telephone is replaced by six ring-shaped magnets, arranged in such a way that their north poles, for instance, are connected with the core, and the other poles touch the front border of the diaphragm (Fig. 126). By this means, the magnetic field is considerably

Fig. 126.—Phelps' crown telephone.

strengthened, and the instrument is very powerful. It is the invention of an American, Phelps, and owes its name to its crown-like form.

Pony-Crown Telephone.—This model, too, is due to Phelps, and is nothing else but a Bell's telephone, whose magnet is bent in the form of a circle (Fig. 127). We find in it, again, the ebonite mouthpiece E, the plate P, a small cylinder of soft iron G fixed on the magnet, and forming the core of the bobbin B.

The apparatus presents nothing special, except its very convenient shape, which allows of its being applied to the ear, or easily suspended when it is not used. It is

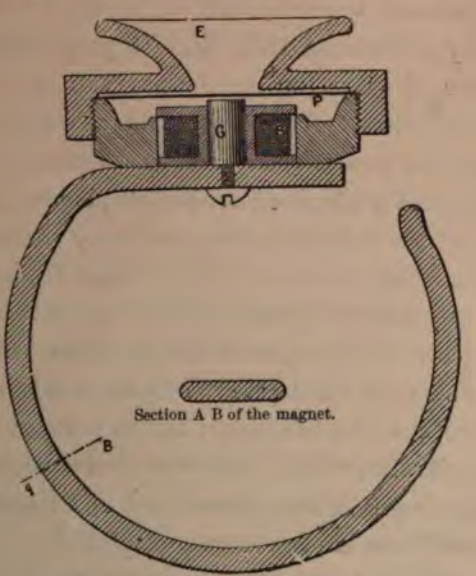


Fig. 127.—Pony-crown telephone.

generally employed for telephonic communications by Edison's system.

Siemens' Electro-Dynamic Telephone.—In this telephone the coil is movable, it is fastened to a membrane, and moves in the magnetic field formed by a powerful electro-magnet energized by an external source. The induction currents are produced by the displacements of the coil in the magnetic field; the action is due to electro-dynamic induction, and not to a change of magnetism of a magnetized bar. The receiver is identical with the transmitter.

Different Models of Bell's Telephone.—We can only briefly mention here a number of modifications of Bell's telephone—

modifications which were effected with the view of increasing the intensity of the sounds emitted by the receiver, although the results have not always been in accordance with the hopes of the inventors.

As early as October, 1877, Wilmot proposed to increase the number of vibrating membranes and of magnets, to increase the intensity of the currents developed under the influence of the human voice. About the same time, Trouvé also constructed a telephone with multiple membranes; but these apparatus did not give satisfactory results. Phelps and Elisha Gray in America, and Cox Walker in this country, constructed apparatus with several membranes. These apparatus gave better results than Wilmot's and Trouvé's, and their description is to be found in Count du Moncel's work on the telephone; but in practice these complicated apparatus, which require a special adjustment for each membrane, have been abandoned, and telephones with a single membrane are exclusively employed.

The snuff-box telephone is nothing but a Bell's telephone in which the magnet is rolled into a spiral, making almost a complete turn; this renders the instrument less voluminous, and gives it the appearance of a small round box.

By fixing a wooden handle of a few centimetres to the side of this box, the apparatus is transformed into a telephone-mirror.

Battery Telephones.

In magnetic telephones, the speaker acts like a real generator of electricity; the mechanical work of the voice is partly transformed into induction currents, and these

currents, on passing into the receiver, make it vibrate synchronically with the membrane of the speaker. The currents sent along the line must, therefore, have a limited intensity, and in no case will the receiver be able to emit more powerful sounds than those emitted before the speaker.

The case is different with battery telephones. In these apparatus, the vibrations of the transmitter are no longer utilized to produce currents, but conveniently to distribute those emanating from a constant source; their intensity is, therefore, only limited by that of the source employed. Under these conditions, the power of the receiver can be very great, and even repeat with more intensity the sounds emitted before the transmitter. The microphone will offer a number of these examples.

All transmitters of battery telephones are founded on the same principle—to utilize the vibrations of a plate, or some such piece, in order to produce a variation of the electrical resistance of a circuit, and consequently to modify to a certain extent the intensity of the electric current traversing that circuit.

This general principle requires the transmitter to be composed of a special substance, with variable resistance, more or less ingeniously arranged in the circuit, and modifying its resistance under the influence of the vibrations it receives. From this results a very simple classification of the battery transmitters, depending on the nature of the substance which is instrumental in producing the variable resistance.

We distinguish three classes of battery transmitters—

1. Liquid transmitters, in which a liquid is employed to produce variable resistance.

2. Transmitters with voltaic arc, in which a thin layer of air and high tension currents fulfil this function.

3. Carbon transmitters, the only important and practical ones, comprising microphones.[1]

We shall only say a few words on the two first classes, which have not given satisfactory results in practice, reserving a larger space for carbon transmitters, which are now exclusively used.

1. *Liquid Transmitters.*

They are, from an historical point of view, the oldest articulating telephones. It has been mentioned that, as early as 1876, Bell and Gray invented an apparatus reproducing speech by varying the resistance of a liquid placed between two platinum points. The same was attempted in a rough sort of way, but without success, by Yeates, of Dublin, in 1865, with the view of improving Reiss' musical telephone.

In 1877, Richmond patented in the United States a liquid telephone similar to Bell's (p. 316), to which he gave the name of electro-hydro telephone.

On the 18th of February, 1878, Salet brought before the Académie des Sciences a telephone with liquid transmitter, in which a small aluminium lever in communication with the battery was fixed to the vibrating plate, and carried at its extremity a small platinum plate; very close to this latter was a second one connected with the line. A layer of liquid separated the two plates.

[1] Since the above was written, Dr. Cornelius Herz has invented a transmitter of solid substances of inferior conductivity, by means of which telephonic transmissions can be effected at a great distance, as for instance on the cable between Brest and Penzance.

"The vibrations of the membrane, trebled or quadrupled in their amplitude, are not altered in their form, owing to the smallness and the lightness of the lever. The variations produced in the liquid mass by the passage of an intense current engender analogous variations in the attractive force of the receiver. The sound transmitted is very clear, and the timbre faithfully preserved. The consonants, however, are not as distinct as those transmitted by Bell's instrument. This inconvenience, however, which makes itself specially felt when the lever is somewhat heavy, might easily be avoided. The electrolysis, moreover, produces a continuous rustling, but without very much interfering with the clearness of the sound."

J. Luvini and Carlo Resio, of Genoa, have also constructed telephones similar in principle.

Luvini's instrument can, by a special arrangement of the transmitter, send differential and alternating currents. The current ceases when the plate is in equilibrium, and the intensity of the currents varies with the extent of displacement of the system above or below this equilibrium. All these apparatus have merely a scientific interest, and are not employed in practice.

2. *Transmitters with Voltaic Arc.*

These telephones have been constructed with the view of obtaining larger variations of resistance than with liquids for the same amplitude of vibration of the diaphragm, but the employment of large resistances such as those of gaseous conductors also necessitates the employment of high-tension currents. Trouvé, who first constructed a telephone of this kind, suggests the use of his elements

with discs moistened with copper sulphate and zinc sulphate. He arranges 400 or 500 of them in series to obtain a sufficient tension.

These apparatus, like the liquid transmitters, have found no practical application.

3. *Carbon Transmitters and Microphones.*

The invention of the first carbon transmitter is due to Edison, who constructed it in 1876, immediately after Graham Bell's discovery. The first microphone is of more recent date, and is due to Hughes, the inventor of the printing telegraph, who exhibited it for the first time in January, 1878, before the officials of the Submarine Telegraph Company.

But the principle which Edison and Hughes have first applied to electrical transmission of sonorous vibrations—we purposely choose this vague and general term—was discovered, in 1856, by Count du Moncel.

It had been believed for a long time that the contact between two metals was sufficient to render them capable of transmitting an electric current, without introducing any resistance in its passage.

After numerous researches on electrical interrupters, Du Moncel was the first to state that pressure exercised at the point of contact between two conductors touching one another, had a considerable influence on the intensity of the resulting electricity.

Du Moncel first of all attributed this effect to a physical cause which had not been properly appreciated; but he was afterwards led to the conclusion that it arose from a larger or smaller amount of pressure of two bodies at their

point of contact. The variation of resistance at the point of contact is the greater the more resistance is offered by the conductors; it also depends upon their degree of hardness, and upon the more or less clean state of their surface. The principle discovered by Du Moncel was applied, in 1865, by Clérac, a French telegraph officer, to a carbon rheostat formed of a tube filled with graphite, in which a movable disc forming the electrode caused, by pressing

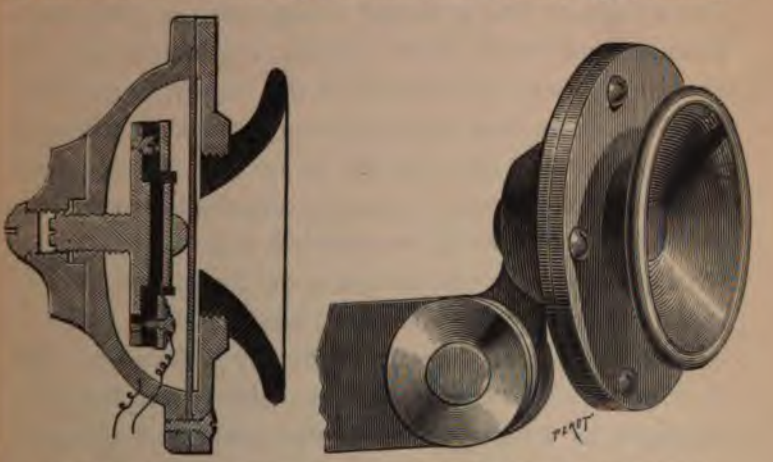


Fig. 128.—Edison's carbon transmitter (model of 1879), in section and perspective.

more or less strongly on the graphite, a considerable variation of resistance in this substance.

Edison's Carbon Telephones.—The original form of this instrument has undergone a great many changes since its first appearance in 1876. The model represented in Fig. 128, in section and perspective, is the one employed in France at the present moment for telephonic communications.

The transmitter consists of an ebonite mouthpiece, a vibrating plate, and a disc of prepared carbon of the size of a shilling piece, placed on a support, which can be

removed from the vibrating plate or brought near it by means of a screw at the back part of the speaker. A small platinum plate with a rounded ivory button is fixed to the upper surface of the carbon plate. The vibrations of the membrane are communicated to the carbon by the small platinum plate; the variations of pressure produced by these vibrations cause a variation of electrical resistance in the carbon, interpolated between the circuit of a battery and a receiver (Bell's, Phelps', Ader's, etc., magnetic telephones), and cause it to vibrate synchronically. In practice, however, the current of the battery, transformed by the speaker into an undulating current, is not sent directly into the receiver, but is localized, traverses the inducing wire of a small induction coil, and leaves through the induced wire, which is connected with the receiver of the opposite station. Before going any further, we have to explain the reasons for this special arrangement.

Use of Induced Currents in Battery Telephones.—The function of the transmitter in battery telephones is restricted, as we have seen, to the production of variation of electrical resistance in the circuit; this variation immediately occasions a proportionate variation, in an inverse sense, in the intensity of the passing current.

For a given vibration, the change in the resistance of the circuit will have a given value, which we will assume, for argument's sake, to be one ohm. If the entire circuit has a feeble resistance—ten ohms, for instance—the variation of one ohm produced in the transmitter will vary the intensity by one-tenth of its total value, and consequently the receiver, which acts under the influence of these variations of intensity, will vibrate with great energy, and speak with a certain force.

If, on the contrary, the total resistance of the circuit is large—1000 ohms, for instance—the variations of intensity will not be more than $\frac{1}{1000}$ of the total intensity, the lengthening of the line itself having weakened it to a considerable degree.

To obtain, therefore, an equally powerful effect, it would be necessary to increase the number of the elements of the battery to a very large extent, and to increase the variations of resistance—a result which is in a certain measure obtained by multiplying the carbon discs as in Navez's telephone, or the microphonic contacts as in Crossley's microphone and in Maiche's electrophone. The employment of a powerful battery is neither practical nor economical, and the number of discs cannot be increased indefinitely, for they introduce their own resistances into the circuit, and the advantage resulting from multiple contacts would thereby be counterbalanced. At a given moment, equilibrium is produced, and, by increasing their number, the effect is more injurious than useful.

Edison cleverly got over this difficulty by employing an arrangement applied already, in 1874, by Elisha Gray to his musical telephone. Instead of causing the current of the transmitter directly to traverse the line, Edison makes it pass into the coarse wire of an induction coil. One of the extremities of the fine, or induced, wire is connected with the earth; the other end is attached to the line, traverses the telephone of the receiving station, and goes into the earth. Two immense advantages are gained by this arrangement. The transmitter now only acts upon a feeble resistance, represented by the battery, the transmitter, and the inducing wire. The variations of resistance of the transmitter have now a considerable relative value. These

variations manifest themselves in the inducing wire by variations of corresponding intensity, and in the induced wire by induction currents of proportional amplitude. But, on the other hand, with reference to the functions of the induction coils, the currents developed in the induced wire acquire in the coil a high tension, which enables them to overcome large resistances, and this property allows of telephonic messages being sent to a considerable distance with the current of three Leclanché's batteries.

Edison's telephone, for instance, acts in the following manner:—The currents of variable intensity, modulated by the transmitter, traverse the inducing wire, and, allowing for the feeble total resistance of the circuit, produce variation of intensity between rather wide limits; the undulating currents then act upon the receiver as in Bell's telephone.

The carbon plate, which is the very essence of the transmitter, deserves special mention. It is made of lampblack obtained by burning petroleum lamps with long wicks in a nearly closed space. The lampblack is afterwards condensed by compressing it lightly under a coining press. It is thus formed into a rather friable plate, but sufficiently compact when kept in position between two platinum plates, and of extreme sensitiveness as regards the variation of its electrical resistance in proportion to the pressure.

Various Modifications of the Carbon Telephone.—It has been mentioned that Navez, colonel in the Belgian artillery, had employed several discs instead of a single one, and we have indicated how far this alteration might be of advantage.

In Pollard and Garnier's telephone, the transmitter

consists of two graphite points, placed on metallic carbon-holders, pressing with a certain regulated force against the vibrating plate. As in Edison's telephone, it is the induced current arising from a small coil which is conveyed to the receiver. Hellesen has constructed a reaction telephone, in which the transmitter is formed by a carbon pencil pressing against the plate, and by a real hollow electro-magnet, whose coarse wire is traversed by the current after this latter has passed through the carbon pencil and the plate. The reactionary effects are due to the strengthening and weakening of the magnetism of the electro-magnet placed opposite the vibrating plate, and are, according to Hellesen, favourable for the action of the apparatus. The circuit of the receiver consists of a long coil of fine wire surrounding the coarse wire of the electro-magnet, and the induced currents developed in this second coil act on the magnetic telephone receiver.

Houston and Thomson also constructed, shortly after Hellesen, two similar telephones, whose peculiarity is that they can act either as transmitter or receiver. A complete description of these two apparatus, which practice has not sanctioned, is to be found in Du Moncel's work on *The Telephone, the Microphone, and the Phonograph.*

Righi's transmitter consists of a plate carrying a flat disc, which exercises a variable pressure on a mixture of powdered graphite and silver, placed in a small trough above the disc. This transmitter can only act horizontally, which is a decided drawback. The receiver is a Bell's telephone of large dimensions, whose vibrating plate consists of a sheet of parchment, in the centre of which a small disc of soft iron is fixed. Two Bunsen elements are sufficient to work the apparatus, which repeats the sound

of a trumpet or a flute in every part of a room. Words can be heard at a distance of three metres (ten feet) from the receiver. For short distances, the receiver is in the same circuit as the battery and the transmitter, but for somewhat longer distances, Righi employs induction coils, like Gray and Edison.

Ader's Electrophone.—This apparatus differs from other battery telephones by some novel and interesting modifications. The transmitter consists of a sort of movable wooden carbon-holder, ending in a saucer-shaped mouthpiece. The extremity of the carbon-holder terminates in a small carbon cylinder, rounded at its extremity, and which presses against a second fixed piece of carbon of larger dimensions. The current traverses the fixed carbon, the small movable carbon, and leaves by a very fine and very elastic wire to rejoin the line. By keeping the apparatus in a vertical position, the circuit is opened; by shaking it, shocks are produced, which manifest themselves in the receiver by an intense noise, which can be heard at a considerable distance; by holding the apparatus in a slightly inclined position, a slight contact between the two carbons ensues, and direct telephonic transmission, without induction coil, is effected with great clearness and force.

The receiver is a drum of fifteen to eighteen centimetres in diameter, closed by a sheet of parchment, on which six small, very thin and very narrow armatures of sheet iron are arranged on a circle of six centimetres in diameter.

Opposite these armatures, six small microscopical electro-magnets are placed, each of which can be separately regulated by means of a screw. These small electro-magnets were first used by Marcel Deprez in his recorders, to overcome the magnetic inertia of larger electro-magnets—an

inertia which causes a delay in the magnetization, and consequently in the registering of the phenomena. The six small electro-magnets are all arranged for tension, and act simultaneously on their armatures, in the same sense and with great rapidity.

With this receiver, words can be heard at a distance of about eighteen feet, by using the transmitter we have described; but its adjustment is very difficult, because the membrane is too sensitive for heat and moisture. We remember a lecture at which the apparatus, although it had been accurately adjusted a few hours previously, absolutely refused to give forth a single sound before a most attentive and well-disposed audience—conduct of which no well-behaved instrument ought to be guilty in public.

Ader now generally employs his telephone with magnetic overcharge as receiver; the results are nearly as powerful as with the electrophone, and infinitely more certain.

Boudet's Telephone.—This system is characterized by the arrangement of the speaker. In order not to describe the apparatus twice, we refer the reader to the medical applications of the microphone by Boudet, of Paris (p. 395). The arrangement of the apparatus as a telephone is slightly different; the disc is fixed on the plate of the speaker, and follows its movements.

Boudet's telephone is very powerful. On using a Bell's telephone with a rather thick plate as receiver, the words can be heard in every part of a room, provided an ear-trumpet is added to the apparatus, as for the phonograph; but this transmitter is, like Ader's receiver, rather capricious, and requires frequent adjustment.

We only mention in passing Bourseul's and Locht Labye's telephones—modifications of the carbon telephones without

any importance. They constitute intermediate systems between carbon transmitters, properly speaking, and microphones.

Blake's Transmitter.—This system, which is now very much used in England with induced currents and Bell's telephone as receiver, has a transmitter of considerable power. The contact which produces the variable resistance is formed by two movable organs independent of the diaphragm, and always in slight contact with one another. The rigidity of one of the parts is replaced by its inertia by fixing the carbon to a heavy mass; the second part of the contact is formed by a small bead of platinum pressed slightly against the carbon by means of a small spring. The contact of the two pieces never being broken, no crackling sounds result from the opening or sudden closing of the circuit. In Fitch's telephone, one of the carbons is placed on felt, which gives a certain elasticity and also prevents the crackling sound. Our space does not allow us to describe a large number of other modifications, which differ from the leading types that have been examined only by some unimportant details. We must, however, say a few words of a new telephone constructed by Hopkins, which is especially remarkable for the facility of its adjustment.

Hopkins' Telephone.—The transmitter consists of a plate of mica A (Fig. 129), on which a small copper vessel B is fixed, enclosing a small carbon cylinder. A vertical carbon pencil F presses against the small carbon cylinder fixed on the plate, and is maintained in this position by the upward pressure of a bath of mercury into which it plunges; the mercury is placed in a glass vessel D, which can be raised or lowered by means of the support E, regu-

lated by a screw. The pressure exercised by the mercury is transmitted to the contact in B, and can thus be very easily regulated. The use of mercury in the apparatus naturally renders it more or less stationary. Figs. 129 and 130 will sufficiently explain the construction of the apparatus, which employs induced currents, like most other carbon telephones.

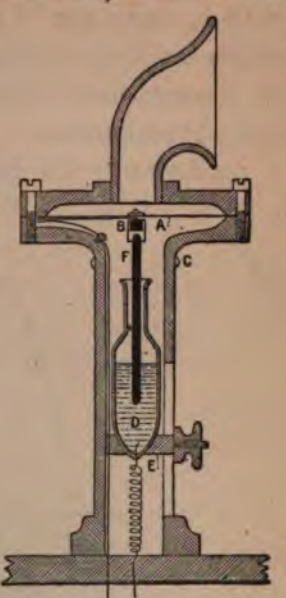


Fig. 129.—Speaker of Hopkins telephone (one-half natural size)

The bell-shaped mouthpiece at the upper end concentrates the vibrations on the plate. The receiver of the station is an ordinary Bell's telephone, whose mouthpiece rests on a second ear-trumpet. By taking up a position

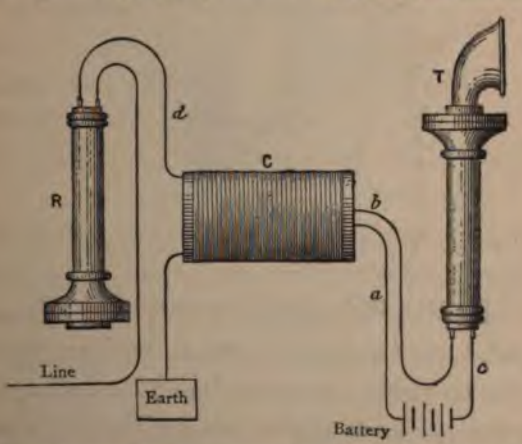


Fig. 130.—Diagram of the mounting of a Hopkins' telephone station.

very close to the apparatus, and shouting "Oh!" into the

mouthpiece, the receiver at the other station can be clearly heard in every part of a comparatively quiet room. This enables the listener to dispense with any sort of commutator, and prevents errors, which are of rather frequent occurrence with other apparatus.

As shown by the diagram (Fig. 130), the two receivers

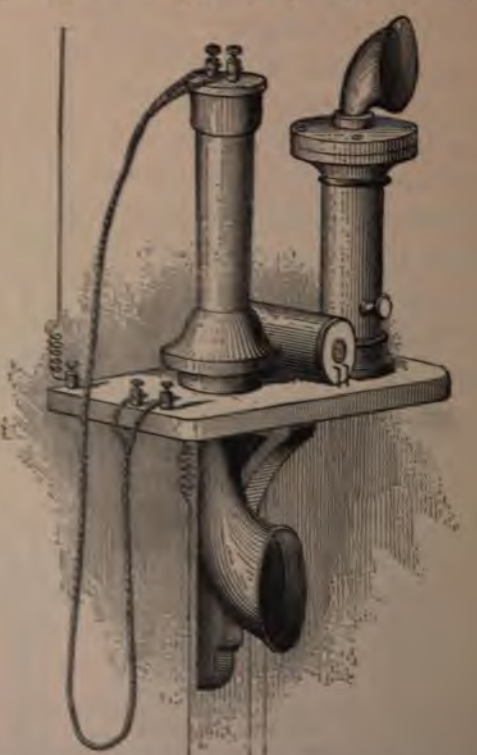


Fig. 131.—Hopkins' telephone (complete station).

are mounted in the same circuit, as well as the induced wires of the two coils. At each station the battery is closed on the telephone T and the inducing wire *a b* of coil C.

Fig. 131 represents the complete arrangement of a station in perspective.

Here we must conclude our list of carbon transmitters, which increase in number every day; and pass on to the examination of transmitters of a special kind and of infinitely greater delicacy.

Microphones and Microphone Speakers.

The microphone is nothing but a telephone transmitter of special form, but it owes its name, which was given it by its inventor, Hughes, to the results it enables us to obtain.

The microphone is in reality an amplifying apparatus of

Fig. 132.—Elementary microphone.

mechanical vibrations of feeble intensity, which it transforms into undulating currents. These undulating currents, sent into a receiving telephone, very often produce sonorous vibrations of much greater intensity than the original source. It performs, therefore, in acoustics, with regard to feeble sounds, the same part as the microscope does in optics as regards small objects.

It will be easier, after having described Hughes' simple

apparatus, to explain how these startling and unforeseen results have been obtained.

The simplest apparatus employed by Hughes in his numerous researches is represented in Fig. 132. Two nails A are fixed on a small horizontal board, at a distance of about one millimetre from one another. The wires X and Y fixed to these nails are connected with a battery B and a telephone, so that the space between the nails forms the only interruption in the circuit. On placing a third nail across the two first, the current passes through the points of contact of the two nails, which form an imperfect contact, to which the apparatus owes all its sensitiveness; and

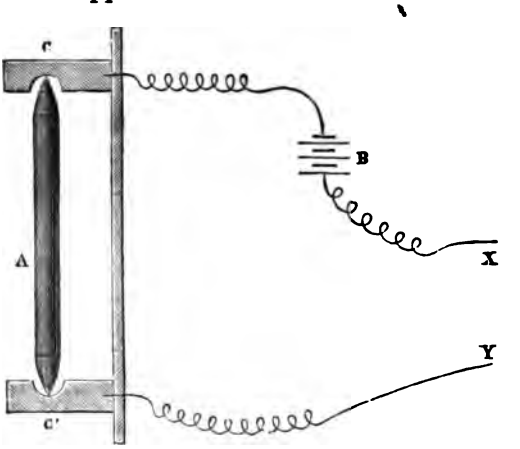


Fig. 133.—Hughes' microphone.

this apparatus constitutes a perfect telephone transmitter. Words spoken, airs sung to this little nail, which can dance on the two others to the sounds or the notes emitted, are instantaneously transmitted to the receiver at the other extremity of the line, with marvellous clearness and power. The effect produced is better still with carbon pencils.

But the most sensitive apparatus which Professor Hughes has constructed, and which has remained, barring a few unimportant modifications, the microphone *par excellence*, is represented in Fig. 133.

It consists of a small pencil of gas carbon A, terminating in a point at each end; the two ends rest lightly between two small circular holes of two pieces of carbon C C′, and

Fig. 134.—Hughes' microphone. The sound produced by the walking of insects heard at a distance.

the carbon pencil has a vertical position; C and C′ are fixed to a thin sounding-board, which is placed on a solid block D (Fig. 134). The pieces C and C′ are connected by the wires X and Y with the battery and the line wire leading to the telephone. This instrument, rough as it looks, is of a surprising and marvellous delicacy.

It converts into sonorous vibrations not only musical notes and words, but the slightest oscillations, and even an imperceptible rustling. The slightest touch, the least friction against the block, is sufficient to produce a grinding noise in the telephone. The point of a small brush rubbing against the block, the fall of a small cotton ball, produce a perfect uproar in the receiver; a fly or any other insect walking on the block D is distinctly heard by a person at a distance of over a mile from the transmitter.

Effects produced in the Microphone.—Now we can appreciate the very slight differences between Edison's carbon transmitter, and the microphone in its simple form as constructed by Hughes.

In both apparatus, the telephonic or microphonic action is produced by variations of electrical resistance, resulting from vibrations communicated to the transmitter.

In Edison's carbon telephone, these vibrations act on a plate which exercises a variable pressure on a disc; in Hughes' microphone, the vibrations effect a change in the points and the surface of contact. The former is intended for transmission of words alone, while the latter is more especially intended for transmission of indistinct sounds. It was, therefore, quite natural at first, that Edison's and Hughes' inventions should be considered as two distinct inventions, as much from the effects realized as for the methods employed.

A number of apparatus have appeared since to fill up the gap which existed between the two apparatus at the time of Hughes' discovery, so that the line of demarcation has quite disappeared, as will easily be seen by referring to Blake's, Boudet's, and Ader's transmitters. We can designate by the generic term of carbon transmitters all

microphones and microphone speakers, which had originally formed a separate class.

Edison himself, in one of his latest models of a carbon speaker, employs an arrangement which is nothing but a microphone speaker of Blake's kind.

Edison's claims concerning Hughes' invention were as little founded as they were courteous, and the whole credit of the invention belongs to Hughes.

It will easily be understood how Hughes' microphone can transmit the faintest sounds by amplifying them, on considering what takes place in a microphonic contact. Let us take, for instance, the insect walking on the block of the microphone (Fig. 134).

Each step taken by the insect produces a slight mechanical movement, not intense enough to produce an impression on the ear, but acting on the microphonic contact; the points of contact are thereby displaced and changed, and variations of intensity produced in the current. These slight mechanical displacements are effected the more easily the less stable the equilibrium of the carbon pencil; and, in fact, the apparatus loses part of its sensitiveness on placing it horizontally. From a philosophical point of view, Hughes' marvellous instrument is very imperfect in the sense that it does not act in proportion to the vibrations which it receives.

Very feeble vibrations are very much amplified, those of greater intensity are reproduced with their real intensity, and powerful sounds are, on the contrary, reproduced with a very much reduced intensity. The apparatus, therefore, acts like a microscope would that enlarged small objects and lessened the big ones. For want of apparatus which allow of a direct measurement of the intensity of sounds—

their pitch alone can be measured at present, and their intensity and timbre approximately estimated—it is impossible to determine how this accommodation of microphonic sounds is effected. It suffices to have mentioned the fact; its accuracy can easily be tested.

Hughes' Microphone (Type Ducretet).—This small instrument enables us to reproduce most of the experiments with the greatest ease (Fig. 135). A small pencil C of gas carbon or graphite, pointed at its extremities, is maintained in a

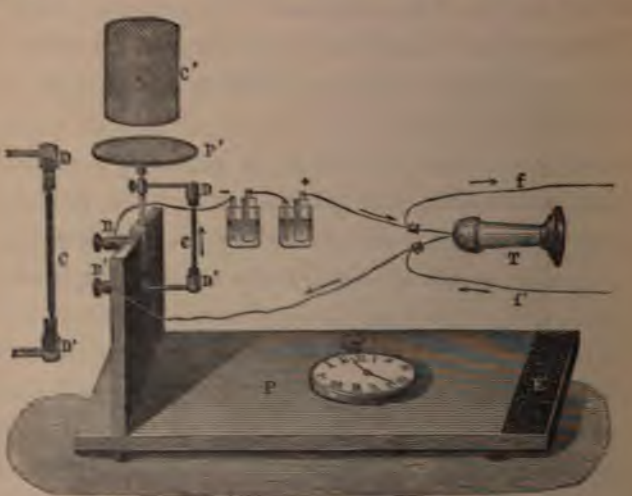


Fig. 135.—Hughes' microphone (type Ducretet).

vertical position between two gas carbons D D'. The support of the upper trough D is arranged in such a way that the equilibrium and the play of the carbon between the troughs, and consequently the sensitiveness of the microphone, can easily be regulated at any moment. The two troughs are in direct communication with the two terminals B B'. The whole is fixed on a small board and a wooden block P. Two indiarubber tubes form the legs

of the block, and insulate it from extraneous vibrations, The slight frictions produced on the rough surface E of a band of emery paper are transmitted by the apparatus.

A battery of two or three Daniells or Leclanchés elements, and a telephone placed at a distance, form a complete circuit, in which the carbon pencil C with its imperfect contacts is included.

Trouvé has constructed a very portative model of a microphone by enclosing the carbon pencil in a small cylindrical box of ebonite.

Crossley and Maiche have constructed microphones with

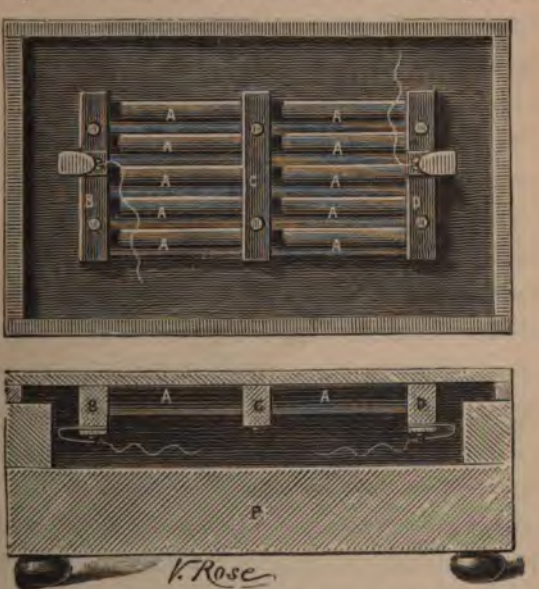


Fig. 136.—View from below and longitudinal section of Ader's transmitter placed on a leaden socket for repetition of theatrical performances.

multiple contacts, as Navez had constructed a carbon transmitter with several discs; but these imperfect contacts, when extensively used, offer the same drawbacks which we have pointed out in Navez's telephone.

Ader's Transmitter.—This microphone, which is now the most extensively used in France, is represented in Fig. 136. It consists of ten small carbon pencils A A arranged in two rows of five, and resting their extremities on three cross-bars of carbon B C D fixed to a small deal board, which receives the vibrations and serves at the same time as cover to the apparatus. It is fastened to a leaden socket P, supported by four indiarubber legs, in order to prevent the concussions of the stage floor from reaching the transmitter.

This precaution is essential, especially at the opera, where the floor is violently shaken by the dancing, and a disagreeable crackling noise would be the consequence. In Ader's apparatus, thanks to the indiarubber legs and the inertia of the block of lead, these concussions do not reach the transmitter, which is only influenced by the sonorous air waves.

Paul Bert and D'Arsonval's Microphonic Transmitter.—In this transmitter all the contacts are mounted for quantity. Each contact is made separately, and is very slight, which ensures sensitiveness; the current is divided between all the contacts, which form as many separate microphones, and diminish the resistance in proportion to their number.

The inventors have constructed several models of these microphones; in some the adjustment is effected by the pressure of mercury, as in Hopkins' telephone (p. 338); in others springs are used, or magnetic attractions which constitute a weightless spring; in others, finally, a weight acts as regulator. Fig. 137 represents this latter system. It consists of a resonance box similar to that of stringed instruments, or a simple ebonite or deal board which carries the series of contacts.

These contacts consist of a number of small cylinders of German silver, which are strung like beads on a common metallic axis, and are suspended in a vertical direction on one side of the box. Their motion is independent, and each of them rests on a transverse bar of carbon, which acts

Fig. 137.—Paul Bert and D'Arsonval's microphone. C, carbons enclosed in German silver tubes; the vibrations of speech are transmitted to the centre by a speaking-trumpet. B, carbon on which the tubes C rest; D and A, binding screws.

as a collector, and receives the vibrations of the resonance box or of the board. The pressure of these carbons on the collector is more or less strong, according to the inclination of the box, which can either be mounted as shown in Fig. 137 or suspended in the room by the two conducting

wires. The current arrives through the upper axis, is divided between the carbon pencils, and leaves by the collector. The number of contacts can be increased at will, as well as the dimensions of the box.

Boudet's Microphone.—In this system the contacts are mounted for tension, instead of being placed on a shunt as in the preceding apparatus. The transmitter, represented in Fig. 138, consists of a mouthpiece E attached to the

Fig. 138.—Dr. Boudet's microphone.

extremity I of a glass tube T of one centimetre diameter, which is itself fixed to a jointed support, so that the whole of the apparatus can be bent at any angle.

The mouthpiece carries an ebonite plate D of one millimetre thickness, to which is fastened a copper rod M^1, which slightly penetrates into the glass tube. In this tube are placed six balls of gas carbon, of slightly smaller diameter

than the tube, so as to allow the balls to move freely inside the tube.

The microphone is completed by a second copper piece M^2 pressing against the bottom R of a hollow breach K by the aid of a small spiral spring which is not represented in the diagram. The screw V fixed on the stirrup Q regulates the pressure of the piece M^2 against the balls. B and B′ are binding screws for battery and line wires. The variations of resistance in the microphone equally affect all the contacts of the balls, because when speaking before the mouthpiece the vibrations are almost instantly transmitted, as in the well-known experiment with the billiard balls.

Before reviewing the different applications which the telephone in its various forms has already received, we must examine, under the title of "special telephones," a number of apparatus in which the telephonic movements—meaning the phenomena which connect the transmitter and receiver —are produced by actions of a very different order from those which have been previously mentioned.

This examination will enable us to establish a more complete theory of the multiple actions which come into play in telephonic transmissions, and accurately to determine the part of each of the organs which constitute these marvellous instruments.

CHAPTER III.

SPECIAL TELEPHONES.

In all the telephones described in the preceding pages, we invariably find a magnetic transmitter, either carbon or microphonic transmitter, sending an undulating current along the line, and this undulating current acting on a receiving telephone, in which we always find as essential parts: 1, a vibrating plate; 2, a magnetic core, and sometimes an electro-magnet; 3, a coil.

None of these organs is indispensable for the reception of articulate sounds in the telephone. Certain receiving apparatus do not even employ a single one of these three organs; in certain telephonic transmissions the words have been heard without a receiver; in others, as in Bell's photophone, transmission is effected without wire, by the help of a luminous ray; in other telephones the receivers assume irregular forms,—the principles on which they are constructed are not based on magnetic action; in some we have physiological actions, as in Gray's receiver; in others, chemical action, as in Edison's electro-motograph, etc. We are going to examine the most important and most original of these apparatus.

Telephones without Vibrating Plate.—The first simplification to be applied to Bell's telephone consists in the suppression of the vibrating plate. In that case words are

no longer distinctly transmitted if the transmitter is a magnetic telephone, but the receiver articulates on using a carbon transmitter and induced currents, as in Edison's telephone. The words, however, are very faint; but Du Moncel, who has made a great many experiments on this subject, has found that the effect is the more intense the more strongly the core is magnetized and the smaller its size.

By employing a thoroughly magnetized watch-spring with a coil of fine wire at the end, Du Moncel has been able to hear spoken words with Bell's magnetic telephone. This fact and a number of others, the results of various experiments, will be considered hereafter.

By the side of these telephones without diaphragm, Bréguet's experiments may conveniently be mentioned, in which the thickness of the membrane has been increased up to fifteen centimetres without depriving the telephone of its power or its faculty of articulation. In the former there is no plate at all, in the latter there is too much of it, and the telephone articulates in either case.

Telephones without Membrane and Magnet. Ader's Experiments.—The presence of a magnetized core in the receiver is not indispensable, and we have seen that Ader's electrophone employs small microscopical electro-magnets of soft iron. Whilst making experiments with these apparatus, Ader was led to construct a receiver composed of one simple iron rod of one millimetre diameter, surrounded by a coil of fine wire, and has been able, under these conditions, to transmit words with great clearness. The small iron wire was stuck into a board, and he found that, by applying a heavy mass to the free end of the wire, the intensity of the sounds was more than doubled.

He then constructed the simple receiver represented in Fig. 139, formed of a handle B, a soft-iron rod C C′ of one millimetre diameter stuck into a pine block P P five centimetres wide, and a small bobbin A rolled round a goose quill. The transmitter employed by Ader was that of his electrophone (p. 336), but the telephone thus constructed will speak with any carbon transmitter. A very amusing

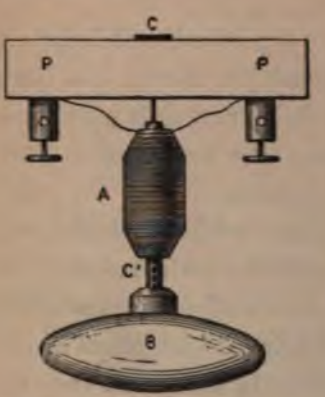


Fig. 139.—Ader's telephone without membrane and magnet.

Fig. 140.—Ader's telephone without magnetic core.

spiritualistic trick can be performed with this little instrument by fastening the iron wire C C′ to the reverse of a table-board, carefully concealing the conducting wires, and having a confederate speaking into the transmitter in a distant room. If the trick is performed in silence, at an advanced hour of the night, the whole table speaks—it can be heard by all those standing round, and the experiment produces the most singular effect on credulous people.

Continuing his experiments, Ader constructed a second, still simpler, telephone (Fig. 140). It consists of a small board A B, and a coil C fastened to the board, round which a fine wire is loosely wound. This apparatus speaks under

the influence of a carbon transmitter and three Leclanché elements. If the spirals of the coil are too close or too thickly coated with gum, the telephone no longer speaks, but on introducing into the coil a nail D, a small iron wire, or a magnetized needle pressing against the board, the words are immediately heard with perfect clearness. On taking the nail out, the telephone again becomes mute.

Dolbear's Telephone.—This instrument presents a great novelty as regards principle. The receiver has no magnet, but has two parallel metallic plates near together and electrically insulated from each other. One of them is connected with the line wire, and the other with the return wire. These two wires are connected with the terminals of the secondary coil of a small Ruhmkorff at the sending station; and the voice of the speaker produces variations in the primary current, on the usual plan of varying the resistance in the circuit of a local battery by variations of pressure. The secondary circuit is not completed, inasmuch as the two plates do not touch; but the opposite electricities which are transmitted to them attract each other on electro-static principles, and the plates are thus made to vibrate in unison with the voice of the speaker at the sending station. The instrument is very effective, and reproduces a whisper with greatly increased intensity.

It is claimed that this invention does away with the disturbance experienced in other telephones from currents in neighbouring wires, inasmuch as such currents will not affect the attraction between the plates. It must be added that the instrument speaks fairly, even when the plate next the ear is disconnected from the wire intended for it, but of course less loudly than when the connection is made.

Telephone without Membrane, Magnet, and Coil.—The following telephone is simpler still:—It consists of a soft-iron rod A (Fig. 141) and a small wooden bar B. By applying the bar B to the ear, and a heavy metallic mass to the other end of wire A, Ader has reproduced words by employing a carbon transmitter. De la Rive, in 1846, had found that sounds could be produced under similar conditions by intermittent currents, but Ader was the first who produced articulate sounds by such simple means.

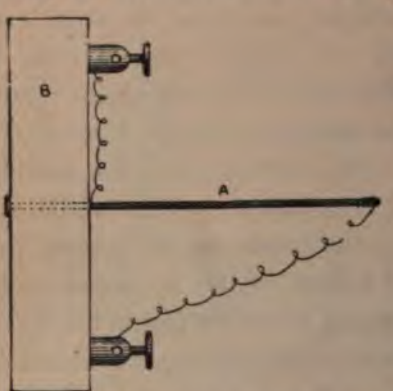


Fig. 141.—Ader's telephone with iron wire.

Since Ader's experiments, Boudet of Paris has constructed a receiving telephone similar to the one represented in Fig. 140, in which the wooden board is replaced by a steel diaphragm. This apparatus reproduces words with the microphone speaker of the same inventor, by employing a single Leclanché. Percival Jenns has also constructed a receiving telephone without membrane or magnet, formed of a coil with iron wire. The apparatus reproduces words by employing Edison's carbon transmitter as speaker.

All these phenomena, as will be seen presently, are explained by Page's effects, which Reiss first applied to his musical telephone.

Preece's Thermo-Telephone. — Wiesendanger, in 1878, ascribed the reproduction of words in certain telephones to the vibratory motions resulting from molecular expansion

and contraction consequent upon variations of temperature, which were caused by currents of variable intensity traversing the telephonic circuit.

The objection raised against this explanation rests on the slowness of calorific effects, which would not be prompt enough to produce vibrations.

Preece, the chief engineer of the London Post Office, has taken up this particular line of study, and, after a number of attempts, has succeeded in constructing a veritable thermo-telephone, consisting of a platinum wire, $\frac{7}{100}$ to $\frac{8}{100}$ millimetre thick and fifteen centimetres long, fixed to a support at one end, and to a disc of cardboard or a vibrating plate at the other end.

This simple apparatus is worked with Edison's carbon speaker; the effects are due to the rapidity with which these fine wires gain and lose their temperature, and to the great expansive power of fine wires of large electrical resistance.

Microphone Transmitters used as Receivers.—Preece attributes to similar causes the phenomena observed for the first time by Hughes, shortly after the discovery of the microphone. Hughes showed that the microphone was reversible, like the magnetic telephone, capable of transmitting as well as receiving vibrations. There was no further need of a plate, or coil, or magnet, or magnetic wire; nothing but two pieces of carbon at each station, connected by two conducting wires with a battery interpolated in the circuit.

The experiment is rather delicate, and all microphones do not in the same degree reproduce the phenomena we have mentioned. Boudet's microphone gives the best results, but the two identical apparatus, speaker and

receiver, must be adjusted to perfection for the purpose. A single Leclanché is then sufficient to produce these effects.

Pollard and Garnier, too, have obtained words from their carbon transmitters, and Carlo Resio, of Genoa, has used his liquid transmitter as receiver. It is impossible, in the present state of science, exactly to explain what happens in these telephonic transmissions.

Blyth's Speaking Microphone.—Into a flat box of thirty centimetres by twenty centimetres, Blyth places some gas cinders and two plates of sheet iron at the extremities of the box; this constitutes the microphone. According to Blyth, by placing two of his microphones in the circuit of a battery of two Grove's elements, words pronounced before one of the microphones can be heard in the other, which acts as receiver. Du Moncel has modified Blyth's apparatus by employing large fragments of coke and two electrodes, one of zinc, the other of copper. By putting water into the box and connecting the two electrodes of the apparatus with the two terminals of a Bell's telephone, a telephonic system is formed, in which the battery serves as transmitter, and the transmitter serves as battery. The variations of interior resistance due to the slight movements of the carbon in this peculiar battery microphone, produce undulating currents, which are transformed into articulate sounds in Bell's telephone.

Edison's Electro-Chemical Telephone.—In this instrument, the receiver alone requires description, for the transmitter is nothing but Edison's carbon transmitter.

Let us first examine the principle of the apparatus, which has enabled Edison to construct his electro-chemical telephone—a principle which was first applied by the inventor to a telegraphic relay, under the name of electro-

motograph. Let us soak a sheet of blotting-paper in a saturated solution of caustic potash, and place it on a metallic plate connected with the positive pole of a battery composed of two or three Leclanchés. On passing a platinum-foil, about one centimeter wide, over the surface of the paper, and exercising a certain pressure on this foil, a resistance to the sliding motion was felt, owing to the friction of the foil against the paper, which possesses a certain roughness of surface. If the platinum-foil, while sliding over the paper, is connected with the negative pole of the battery, the resistance to the sliding will be diminished to a very great extent; the electric current has, therefore, the effect of smoothing, lubricating or, as it were, of lathering the rough surface of the paper—in other words, it diminishes the coefficient of friction between the platinum-foil and the surface of the paper. This effect of the electric current is proportionate to the intensity of the current, it commences and ceases with it, and is so sensitive that the feeblest currents, those for instance which do not act on an electro-magnet, are rendered quite perceptible.

It is very difficult clearly to explain this phenomenon; for our purposes it suffices to note the effect, and to remember that an electric current of variable intensity can produce a variable sliding motion, proportionate to the intensity of the current. This fact being well established, it will be easy to understand the working of Edison's receiver, of which Figs. 142 and 143 represent the interior view and diagram. A thin plate of mica, eight to nine centimetres in diameter, carries in its centre a platinum plate C, which presses against the cylinder A with a constant pressure, due to the spring S, and regulated by the screw E.

The cylinder A is made of a paste consisting of lime, caustic potash, and a small quantity of mercuric acetate. This paste acts the part of the paper soaked in potash in the preceding experiment.

The cylinder turns with a regular motion by means of

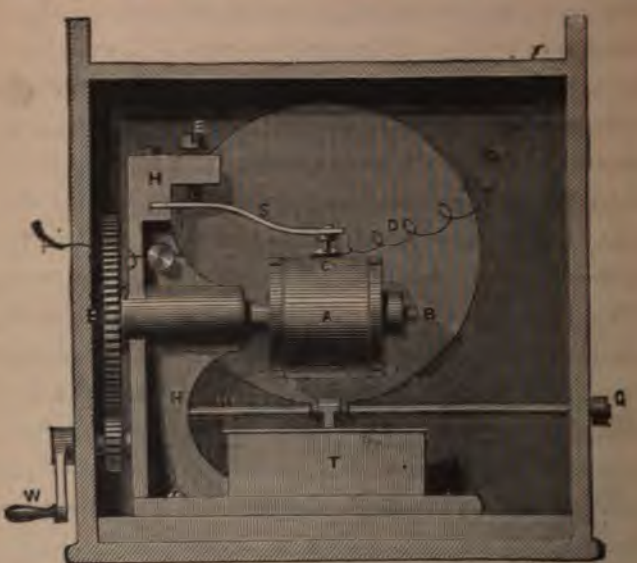


Fig. 142.—Interior view of Edison's electro-motograph. A, cylinder of lime and caustic potash; B, axle of the cylinder set in motion by the winch-handle W; C, platinum plate fixed to the mica membrane; D, line wire; E, regulating screw of the spring S; H, support; S, spring for regulating the pressure on plate C; T, reservoir containing a solution of potash; G, lever for working the moistening roller.

a system of multiplying wheels, and of the handle W. This system is replaced by a clockwork movement in more recent apparatus.

The electric current coming from the transmitter arrives by the support H, traverses the cylinder A coated with the paste, and the platinum plate, and leaves by the wire D to go into the ground. By turning the cylinder A (Fig. 143)

in the direction of the watch-hands, the friction between the plate C and the surface of the cylinder A produces a traction on the plate C. The mica disc, on account of its elasticity, will take up a certain position of equilibrium, which will depend on the traction of the plate C, and consequently on the friction between A and C; each variation in the current which traverses A and C will thus produce a variation in the traction of plate C; this will cause a certain displacement of the mica disc, which will thus vibrate synchronically with the undulating current, and consequently synchronically with the membrane of the transmitter.

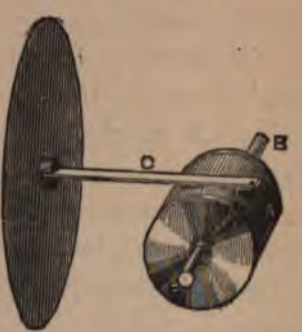


Fig. 143.—Diagram of Edison's electro-chemical receiver.

The vibratory motion of the mica disc is, therefore, not directly obtained by the electric current, but is produced mechanically by the rotation of the cylinder A. The current only produces a certain stoppage, resulting in a variation of the sliding motion, which explains the great power of the apparatus.

On the other hand, the mica disc, possessing little inertia and a considerable elasticity, effectually transmits the impulses received by the plate C. It need scarcely be mentioned that when the handle is not turned the telephone does not act.

Rotation may be effected in either sense. The platinum plate C acts according to the circumstances, either by pulling or by pushing the mica disc. The substance with which the cylinder A is coated must always remain moist, and this result is obtained by raising from time to time

a small roller immersed in a solution of caustic potash, which is contained in the reservoir T (Fig. 142).

In more perfect models, the cylinder is formed of a composition which can remain dry, and this simplifies the working of the electro-chemical telephone to a considerable extent.

The Hand as Receiving Organ of a Telephonic System.—The apparatus capable of transforming the vibratory current emitted by a battery transmitter can assume, as we have already stated, the most singular and most unexpected shapes.

On pursuing his experiments on the transmission of musical sounds, Gray was accidentally led to construct a telephone in which the hand of the operator acted as receiver.

The phenomenon was first observed by Gray on the zinc lining of a bath, and the following is the author's description of the experiment and the apparatus to which it led:—

"My nephew was playing with a small induction coil, and, according to his expression, was giving shocks to amuse the little children. He had connected one of the extremities of the induced circuit with the zinc lining of an empty bath. Holding with his left hand the other extremity of the coil, he touched the zinc with his right hand. As he was thus establishing contact, his hand was for a short time sliding along the edge of the bath. At that moment I heard a sound issuing from beneath his hand at the point of contact. This sound seemed to me of the same pitch and the same quality as that of the interruptor or vibrating electrotone of the apparatus, which I heard likewise.

"Immediately I took the electrode into my hand, and on

repeating the operation, I found, to my great surprise, that, by rubbing hard and fast, I produced a clearer sound than that of the interruptor.

"Following up the idea suggested by the experiment of the bath, I constructed several apparatus with metallic plates for the reception of a sound by means of manual friction. An easy method for obtaining this result is the following:—

"The instrument is composed of a metallic support of sufficient weight to maintain it fixed during the operation. A horizontal axis resting on pads is mounted on the support. One of the extremities of the axis carries a winch, with a handle made of an insulating substance; to the other extremity a cylindrical sounding-box of thin wood is fixed, the surface of which has a metal coating of convex form, in order to render it more solid. This box has an opening in the centre, in order to increase its sonorous qualities. The box is in electrical communication with the metallic support by means of a wire. If the operator connects the metallic coating with the earth by the intermedium of the support, and, seizing with one hand the extremity of the line, presses his fingers against the box, which he turns with the other hand by means of the winch handle, the sound emitted at the extremity of the line is distinctly heard in every part, even of a large room. These conditions being carefully observed, the more rapid the motion imparted to the plate the clearer are the musical sounds, the slower the motion the softer are the sounds. When the motion ceases, the sound also ceases completely."

Antoine Bréguet's Mercury Telephone.—Bréguet's apparatus utilizes electro-capillary forces and the electric

currents produced by them. The phenomenon which led to the construction of this instrument is absolutely reversible; the transmitter and the receiver are, therefore, two identical apparatus.

The mercury telephone differs from Lippmann's electrometer only by its being of simpler construction and of smaller size.

The point of a capillary tube T (Fig. 144) containing mercury M, plunges into a vessel V. The vessel is partly filled with mercury M', and partly with acidulated water A; the capillary point does not reach the mercury, and only dips into the dilute acid.

Two platinum wires P and Q communicate respectively with the mercury M and the mercury M'.

If the two wires are connected with one another, the level of the mercury in the capillary tube will be established at an invariable height. But if an electrical source is interpolated in the circuit of the platinum wires, the level will assume another position of equilibrium, depending on the potential of this source.

In short, a definite level of the mercury will correspond to each difference of potential. Above the mercury M is a layer of air S, whose pressure evidently varies every time the level of mercury itself varies.

The apparatus is reversible, that is to say, if by some modification of the pressure S the level of the mercury suffers displacement, a difference of the potential or, in other words, an electro-motive force will be established in he two conductors P and Q.

Let us now couple together two similar apparatus by connecting the wires P and P_1, Q and Q_1, as shown in Fig. 144. If pressure is exercised at S, an electro-motive force

corresponding to that pressure will be produced in the circuit, and this electro-motive force will produce a change in the level of the mercury M_1 of the second apparatus, and consequently a change in the pressure at S_1.

On speaking above the membrane B stretched across tube T, the air contained in this tube enters into vibration. These vibrations are communicated to the mercury, which changes them into variations of electro-motive force, and these variations engender in the receiving apparatus exactly corresponding vibrations of the mass of air S_1, so that, if

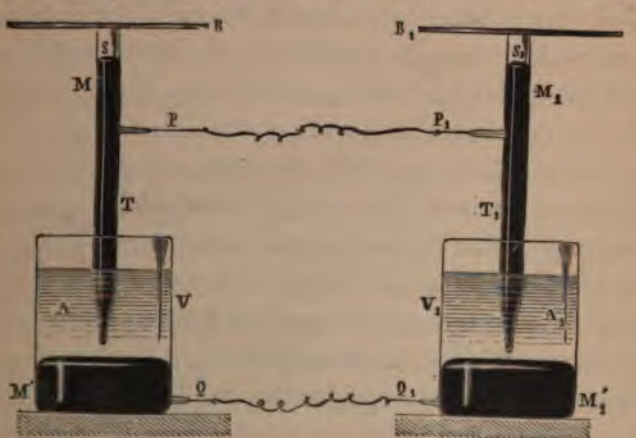


Fig. 144.—Brégnet's mercury telephone.

the ear be placed above the membrane B_1, stretched across tube T_1, all the words pronounced into the tube T will be heard.

Instead of making use of displacement of mercury, displacement of the glass tubes containing it may be utilized, these latter being less voluminous. It is clear, in fact, that the relation of the two attracting and attracted volumes must be as different as possible in order to be able to consider one of the two masses as immovable and, con-

sequently, the other mass as influenced by a maximum displacement.

Telephone without Receiver.—Some very curious experiments made by a French officer of the Engineers at Lunéville, have shown that the words emitted by the transmitter can be heard at the receiving station without any telephone whatever. M. Crépaux gave the following account of these experiments at a meeting of the Société d'Encouragement on the 13th of June, 1879:—

"There exists at Lunéville a telephonic system established under rather primitive conditions. The line wire is of galvanized iron, three millimetres thick, and tightly stretched. It is fixed to a post at the top of a hay-loft, and runs in an obtuse angle along the chimney-stack of a neighbouring house at a distance of about ten metres. The chimney-stack naturally corresponds with the fireplace of a room in the first floor of the building. On speaking into the telephone from one station to the other, not only the receiver speaks and can be heard on holding it close to the ear, but, and this is most inexplicable, the chimney along which the wire runs speaks, the fireplace speaks, and a person lying in bed in the room hears from his bed all the words transmitted to the wire more distinctly than those who at the end of the line use the receiving apparatus. It is impossible to deny this fact, of which I have been a frequent witness. The wire of the chimney-stack has been insulated by glass plates, and yet the words have been heard as before; at the most remote station, at a distance of about 200 to 250 metres, a similar fact has been observed.

"The earth wire follows in its path a zinc drainage pipe; this pipe has ramifications leading to a flag-stone: the flag stone speaks.

"I have been told that at each connecting point the line wire speaks; by bending it several times round a nail fixed in the wall, the knot thus produced speaks.

"It is probable that the fact, which I warrant to be correct, is only produced in the neighbourhood of the point of connection and of contact."

These experiments, in which the active agents have an extremely feeble power, show what a marvellously sensitive and delicate organ our ear is.

We have also to mention Watson's and Ader's telephonic transmissions with open circuit, in which the effects seem to be due to phenomena of charge and condensation as yet imperfectly known; and finally, Graham Bell's marvellous new discovery, which reaches us at the moment of going to press, and of which we can only say a few words.[1]

Graham Bell and Sumner Tainter's Photophone or Optical Telephone.—Experiments dating back as far as 1872 have shown that selenium is a body extremely sensitive to the influence of light, and that this influence manifests itself by modifying the electrical resistance of selenium. Bell and Tainter, after numerous experiments, succeeded in intensifying this sensitiveness, and have constructed an apparatus to which they gave the name of photophone, which enables them to transmit words to a distance by aid of a luminous ray.

For this purpose, the rays of a powerful and constant luminous source—the sun, for instance—have been thrown on a thin and highly polished mirror. On speaking behind

[1] This was written in 1880, at a time when Graham Bell's new discovery was known to Hospitalier only by a short notice in some newspaper or periodical. Following the author's description, I have therefore added a detailed account, in Graham Bell's own words, as given at the Boston meeting of the American Association.—(The translator.)

this mirror its wave is modified in such a manner that the reflected rays are dispersed according to the vibrations of this plate and vary in intensity in a given direction.

At the receiving station the luminous rays of variable intensity strike a parabolical mirror, which concentrates them in its focus. a cylinder of selenium, specially prepared for the purpose, is placed in the focus of the mirror. This selenium modifies its electrical resistance according to the luminous intensities which strike it, and as it is placed in the circuit of a battery and of a Bell's telephone, it acts like a genuine microphone in changing the intensity of the current in the circuit, and produces articulate sounds in the telephone.

This result is simply marvellous, and is another proof—where none, however, was needed—of the ingenuity of the inventors.

Graham Bell's Account of the Photophone.—After a few introductory sentences, Graham Bell goes on to say, "We (Graham Bell and Sumner Tainter) have found this property—sensitiveness to light—in selenium, gold, silver, platinum, iron, etc., and the only substances from which we have not obtained results are carbon and thin microscopical glass. We find that when a vibratory beam of light falls upon these substances they emit sounds—the pitch of which depends upon the frequency of the vibratory change in the light. We find, further, that when we control the form or character of the light-vibration on selenium, and probably on the other substances, we control the quality of the sound, and obtain all varieties of articulate speech. We can thus, without a conducting wire as in electric telephony, speak from station to station, wherever we can project a beam of light. We have not had opportunity of testing

the limit to which this photophonic influence can be extended, but we have spoken to and from points forty-three metres apart; and there seems no reason to doubt that the result will be obtained at whatever distance a beam of light can be flashed from one observatory to another."

Graham Bell now gives the history of the discovery of selenium and tellurium, where we need not follow him. He then goes on to describe the properties of the two metals, and how the sensitiveness of selenium to light was determined by a large number of experiments made by Willoughby Smith, Professor Adam, Siemens, and others. "All observations by these various authors had been made by means of galvanometers (measuring the electrical resistance of selenium, which is greatly diminished by the influence of light); but it occurred to me that the telephone, from its extreme sensitiveness to electrical influences, might be substituted with advantage. Upon consideration of the subject, however, I saw that the experiments could not be conducted in the ordinary way, for the following reason:— The law of audibility of the telephone is precisely analogous to the law of electric induction. No effect is produced during the passage of a continuous and steady current. It is only at the moment of change from a stronger to a weaker state, or *vice versâ*, that any audible effect is produced, and the amount of effect is exactly proportional to the amount of variation in the current. It was, therefore, evident that the telephone could only respond to the effect produced in selenium at the moment of change from light to darkness, or *vice versâ*, and that it would be advisable to intermit the light with great rapidity, so as to produce a succession of changes in the conductivity of the selenium corresponding in frequency to musical vibrations within

the limits of the sense of hearing. For I had often noticed that currents of electricity, so feeble as to produce scarcely any audible effects from a telephone when the circuit was simply opened or closed, caused very perceptible musical sounds when the circuit was rapidly interrupted, and that the higher the pitch of sound the more audible was the effect. I was much struck by the idea of producing sound by the action of light in this way. Upon further consideration, it appeared to me that all the audible effects obtained from varieties of electricity could also be produced by variations of light acting upon selenium. I saw that the effect could be produced at the extreme distance at which selenium would respond to the action of a luminous body, but that this distance could be indefinitely increased by the use of a parallel beam of light, so that we could telephone from one place to another without the necessity of a conducting wire between the transmitter and receiver. It was evidently necessary, in order to reduce this idea to practice, to devise an apparatus to be operated by the voice of a speaker, by which variations could be produced in a parallel beam of light, corresponding to the variations in the air produced by the voice."

The inventor then describes some unsuccessful attempts, and after that the preparation of the selenium cells used in the instrument. These cells are small cylinders of brass coated with selenium. "The mode of applying the selenium is as follows:—The cell is heated, and when hot enough, a stick of selenium is rubbed over the surface. In order to acquire conductivity and sensitiveness, the selenium must next undergo a process of annealing.

"We simply heat the selenium over a gas stove and obscure its appearance. When the selenium attains a

certain temperature, the beautiful reflecting surface becomes dimmed. A cloudiness gradually extends over it, somewhat like the film of moisture produced by breathing upon a mirror. This appearance gradually increases, and the whole surface is soon seen to be in the metallic, granular, or crystalline condition. The cell may then be taken off the stove and cooled in any suitable way. When the heating process is carried too far, the crystalline selenium is seen to melt. Our best results have been obtained by heating the selenium until it crystallizes, and continuing the heating until signs of melting appear, when the gas is immediately put out. The portions that had melted instantly recrystallize, and the selenium is found upon cooling to be a conductor, and to be sensitive to light. The whole operation only occupies a few minutes."

After saying that they constructed about fifty forms of apparatus for varying a beam of light in the manner required, and giving a short account of several of these forms, Graham Bell continues—

"The best and simplest form of apparatus for producing the effect consists of a plane mirror of flexible material, such as silvered mica or microscopic glass. Against the back of this mirror the speaker's voice is directed. The light reflected from this mirror is thus thrown into vibrations corresponding to those of the diaphragm itself.

"In arranging the apparatus for the purpose of reproducing sound at a distance, any powerful source of light may be used; but we have experimented chiefly with sunlight. For this purpose a large beam is concentrated by means of a lens upon the diaphragm mirror (Fig. 145), and, after reflection, is again rendered parallel by another lens. The beam is received at a distant station upon a parabolic

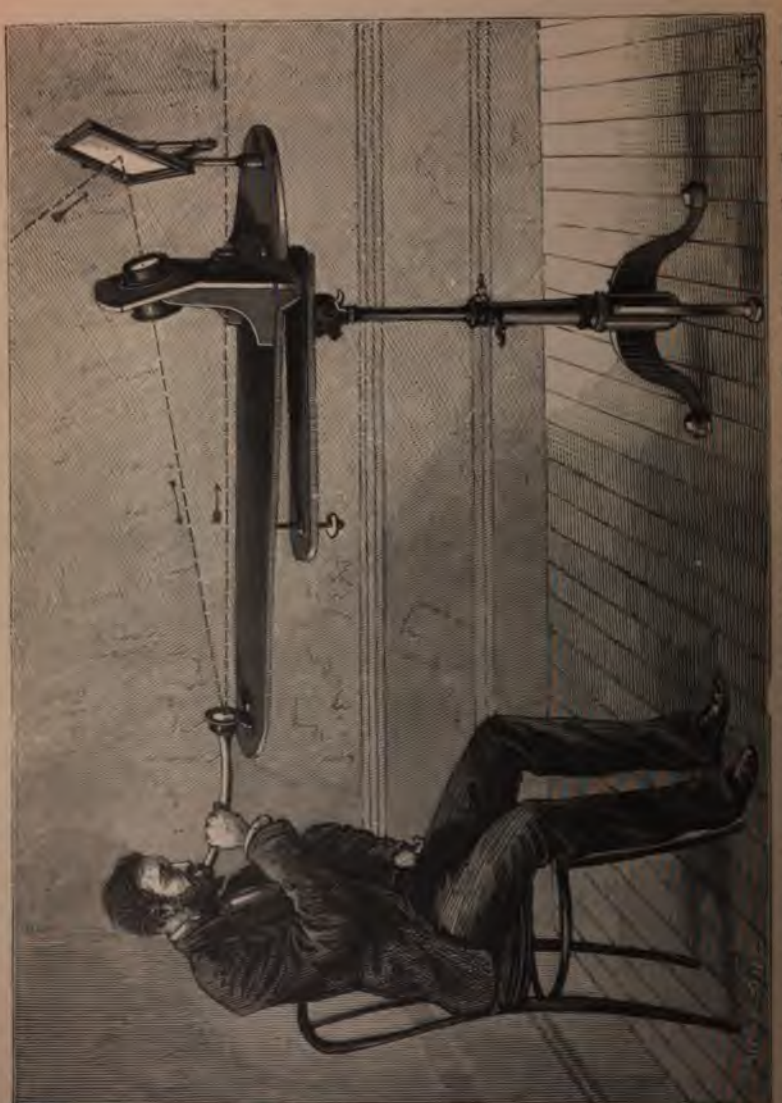


Fig. 115.—Graham Bell and Sumner Tainter's articulating photophone. After reflection on the vibrating mirror of the speaker, the luminous ray, indicated by a dotted line, is directed towards the distant receiver.

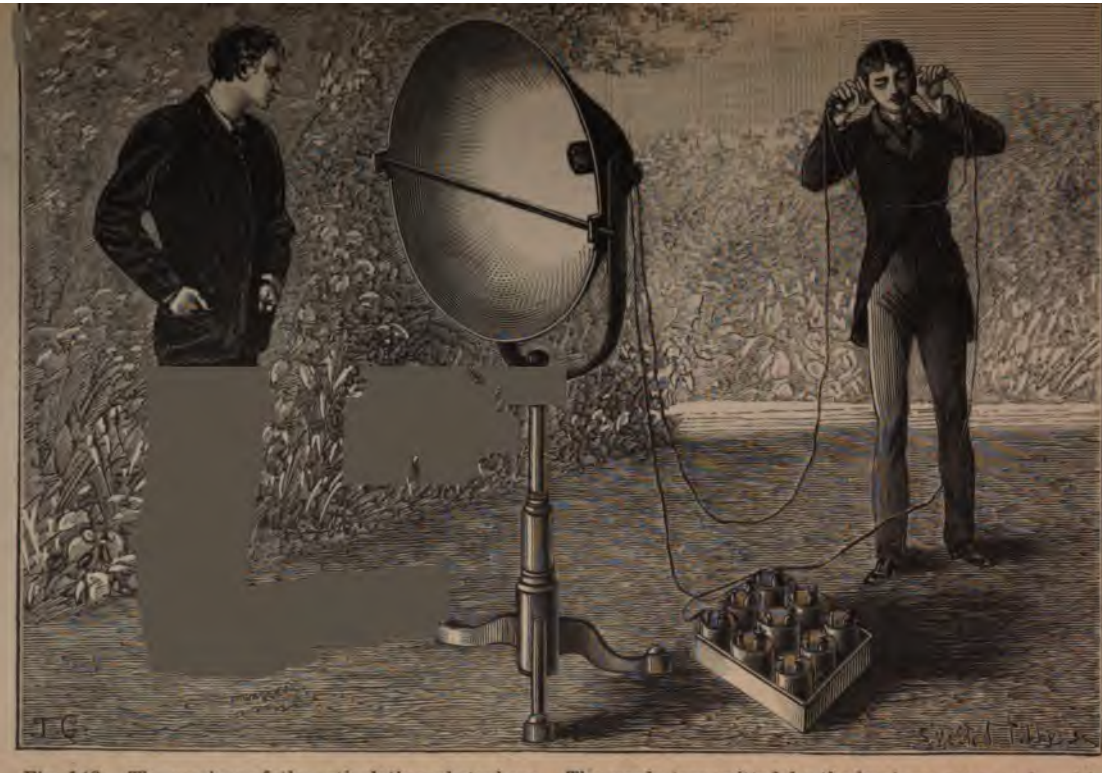


Fig. 146.—The receiver of the articulating photophone. The words transmitted by the luminous rays are heard in the telephones connected to the apparatus.

reflector (Fig. 146), in the focus of which is placed a sensitive selenium cell, connected in a local circuit with a battery and telephone. A large number of trials of this apparatus have been made, with the transmitting and receiving instruments so far apart that sounds could not be heard directly through the air."

After describing one of these experiments, he continues—

"By such experiments we have found that articulate

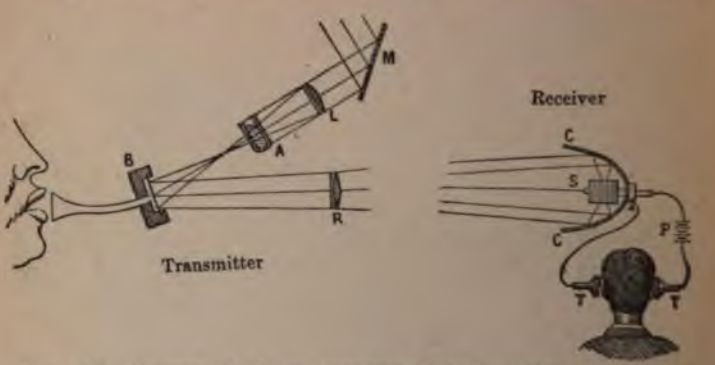


Fig. 147.—Diagram of the articulating photophone (after a sketch by Graham Bell). *Transmitter:* M, mirror for the projection of solar light; L, achromatic lens; A, transparent vessel containing alum; B, support of the vibrating mirror; R, lens for rendering reflected rays parallel. *Receiver:* C C, parabolical mirror of silvered copper; S, prepared selenium cell; P, battery; T T, telephones.

speech can be reproduced by the oxy-hydrogen light, and even by that of a kerosene lamp. The loudest effects obtained from light are produced by rapidly interrupting the beam by the perforated disc. The great advantage of this form of apparatus for experimental work is the noiselessness of its rotation, admitting the close approach of the receiver without interfering with the audibility of the effect heard from the latter; for it will be understood that musical tones are emitted from the receiver when no sound is made at the transmitter. A silent motion thus produces a sound. In

this way, musical tones have been heard even from the light of a candle. When distant effects are sought, another apparatus is used. By placing an opaque screen near the rotating disc, the beam can be entirely cut off by a slight motion of the hand, and musical signals, like the dots and dashes of the Morse telegraph code, can thus be produced at the distant receiving station."

Tellurium and Lampblack Radiophone.—Professor Adams showed that tellurium, like selenium, changes its resistance under the influence of light, and Bell and Tainter tried to replace the selenium by tellurium in their photophonic receiver. The receiver thus constructed, although it gave no indication of its sensitiveness with a reflecting galvanometer, gave sounds in a telephone. Bell made an alloy of selenium and tellurium, which, on account of the extreme electrical properties of the two bodies, ought to have had mean properties. Considering the extensive molecular motions produced by the action of an intermittent ray on lampblack, Tainter thought that an analogous variation would be produced in the passing current, and that it might be possible to replace the selenium by lampblack in the electric receiver.

Experience has confirmed this idea, and the discovery is of vast importance, taking into account the very high price of selenium and tellurium. Fig. 148 represents the lampblack element, which has given the best results. A mirror is coated with a layer of silver, and the coating is removed so as to form a zigzag line with two perfectly distinct parts, which have the appearance of two combs the teeth of which fit into each other. Each comb is attached to a screw, which enables us to interpolate the element in an electric circuit.

The surface is then blackened, so as to fill the whole interval between the teeth of the two combs with lampblack. On connecting the lampblack element with a telephone and a battery, and exposing it to the influence of an intermittent ray, an intense musical sound is produced in the telephone. This result seems rather due to the physical conditions of the conducting substance than to its nature, and any metal in a spongy state produces similar effects.

Fig. 148.—Lampblack element producing a sound under the influence of an intermittent ray or an intermittent current.

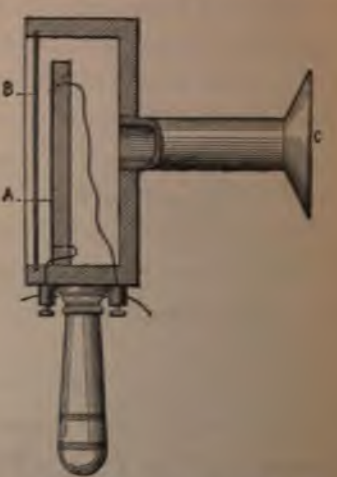


Fig. 149.—Arrangement of the apparatus for the simultaneous action of an intermittent electric current and an intermittent ray.

By employing an induction coil the effects are intensified, and the sensitive elements can be employed as well for the production of articulate speech as for musical sounds.

The lampblack element itself reproduces sounds when traversed by an intermittent electric current, and can even be employed as telephonic receiver for the reproduction of articulate sounds.

Fig. 149 shows the arrangement for a very interesting

experiment based upon these two properties. When an intermittent current traverses the lampblack element A, or when an intermittent ray is thrown on the element through the mirror B, a powerful sound can he heard on applying the ear to tube C. By the simultaneous action of an intermittent current and an intermittent ray, two distinct musical sounds are obtained, which produce a throbbing noise when their pitch is about the same.

With this we must conclude our review of special telephones, whose forms are innumerable, like the active agencies which they employ; our intention was simply to describe the latest and most interesting.

After this examination, it will be easier to establish a theory, if not complete, yet at least more accurate, of the telephone—a theory which, since Graham Bell's marvellous discovery, has made rapid strides, and has given a new impetus to acoustic research by placing a powerful instrument of observation in the hands of the observer.

Theory of the Telephone.—The theory of the transmitter presents no difficulty, and has been explained several times in the preceding pages; we need not refer to it again. The discussions which arose on the theory of the telephone especially referred to the receiving apparatus. How does a receiver—Bell's telephone, for instance—transform an undulating current into an articulate sound? What are the physical phenomena which bring about this transformation?

We have admitted as a provisional theory, convenient for the explanation of the apparatus, that the undulating current produced in the receiver a successive strengthening and weakening of the magnetic force of the magnet, which manifested itself by greater or lesser attractions of the plate, which then vibrated synchronically with the undulations

of the current and the magnetic power of the magnetized bar.

This plausible explanation is sometimes verified in battery telephones with carbon transmitters, but it is inadmissible with Bell's telephone. Count du Moncel, who from the outset rejected this explanation, has seen his ideas partly confirmed by the numerous experiments which have followed Bell's invention; nowadays his theory is almost universally adopted, and we are going to put it before our readers in a few words.

Numerous experiments and measurements made by Warren de la Rue, Brough, Galileo Ferrari, and others, have proved that the intensity of the currents developed by Bell's telephone does not exceed that of a Daniell's element after having traversed 10,000,000 kilometres of telegraph wire—that is to say, 100,000,000 ohms—which represents a telegraphic circuit of a length equal to 250 times the circumference of the earth.

This makes it very difficult to believe that the difference of magnetism produced in the magnetized bar by currents of such feeble intensity could manifest themselves by variations in the attraction of the vibrating plate placed at a distance.

Bréguet's experiments, made with plates of fifteen centimetres thickness, and Ader's, who employed no plate at all, put an explanation based on magnetic attractions alone out of the question.

Page's experiments have shown that an iron rod placed in a bobbin vibrates under the influence of interrupted currents. Reiss' musical telephone is, as we have seen, a practical application of this phenomenon. These vibrations are occasioned in the very core itself by successive changes

of magnetization of the core. In Bell's telephone the core vibrates longitudinally under the influence of the undulating current traversing the bobbin.

This second phenomenon, however, is not sufficient to explain Ader's telephone without magnetic core; a third influence must be admitted, due to the action of the spirals of the helix upon each other. In other cases the helix and the magnetized bar act upon one another, and this contributes to the production of sounds.

Sometimes a fifth influence of purely mechanical origin is at work, manifesting itself in the same way as the transmission of sound through solid bodies. Crépaux's experiments (p. 366) are the most curious and most remarkable instance of this.

In a given telephone, the five agencies which have been mentioned are not all at work with the same energy; sometimes one of them is predominant, others disappear completely; in certain cases all five act, but not with the same degree of energy. In certain telephones the vibration of the plate itself plays a rather important part in giving to the transmitted sounds a very peculiar timbre, but this is chiefly the fault of the transmitter, which sends a deformed undulatory current along the line by the very action of its vibrating plate.

And yet it would be a mistake to conclude from all this that telephonic currents coming from a magnetic transmitter cannot produce vibrations in a diaphragm by purely magnetic attraction. Ader's alarum, for instance, acts with currents developed by Gower's magnetic telephone. Here we have a direct magnetic action producing a veritable attraction.

These various considerations will sufficiently show that

the theory of the telephone is very complicated, and that it is very difficult exactly to define the part played by each of the agencies at work. The numerous discussions on this subject arise from the fact that the influence of each of these agencies has been exaggerated individually, and at the expense of the others. The truth is that they are simultaneous, and manifest themselves with a different degree of intensity for each particular case. In any case, it is quite certain that molecular action, which is as yet so imperfectly known, plays an important part in acoustic phenomena, and that the telephone, like the phonograph, will give a new impetus to research in this direction, by opening up for that branch of physical science a new horizon as vast as it is unknown.

Before passing on to the applications of the telephone, we must give a brief account of an apparatus which created considerable sensation at the time of its invention by Edison in 1877, and which has been mentioned in the preceding lines, namely:—

The Phonograph.[1]—This apparatus consists chiefly of a steel point attached to the disc of a telephone and pressing lightly on a strip of paper passed beneath the point at a uniform rate. The vibrations of the disc are thus recorded, and can be translated.

The apparatus consists of a mouthpiece, across the inner orifice of which is a metal diaphragm, and to the centre of this diaphragm is attached a point, also of metal. A brass cylinder, supported on a shaft which is screw threaded, turns in a nut for a bearing, so that when the cylinder is caused to revolve by a crank, it also has a horizontal travel in front of the mouthpiece. It will be clear that the point

[1] From *Nature*, January 3, 1878.

on the metal diaphragm must, therefore, describe a spiral trace over the surface of the cylinder. On the latter is cut a spiral groove of like pitch to that on the shaft, and around the cylinder is attached a strip of tinfoil. When sounds are uttered before the mouthpiece, the diaphragm is caused to vibrate, and the point thereon is caused to make contacts with the tinfoil at the portion where the latter crosses the spiral groove. Hence the foil, not being there backed by the solid metal of the cylinder, becomes indented, and these indentations are necessarily an exact record of the sounds which produce them.

It might be said that at this point the machine has already become a complete phonograph, but it yet remains to translate the remarks made. The sending mechanism is nothing but another diaphragm held in a tube on the opposite side of the machine, and a point of metal which is held against the tinfoil on the cylinder by a delicate spring. It makes no difference as to the vibrations produced, whether a nail moves over a file or a file moves over a nail, and in the present instance it is the file or indented foil strip which moves, and the metal point is caused to vibrate as it is affected by the passage of the indentations. The vibrations, however, of this point must be precisely the same as those of the other point which made the indentations, and these vibrations, transmitted to a second membrane, must cause the latter to vibrate similarly to the first membrane, and the result is a synthesis of the sounds which, in the beginning, we saw as it were analyzed.

It is to be regretted that some sounds are very indistinctly rendered by the instrument; for instance, the two words *bite* and *bout* could not be distinguished, and some words like *see* disappear altogether. The mechanical

obstacle of the tinfoil, which has to be indented and offers too much resistance, seems to be the cause of this.

The invention is highly interesting, the effects produced are sometimes startling (as in cries, coughs, laughter, music), the philosophy of the process (taking a permanent impression of a very complex compound vibration, and taking it as a mould for reproducing that vibration) is exceedingly attractive, but at present the instrument has not risen beyond a lecture illustration or a philosophical toy.

CHAPTER IV.

THE APPLICATIONS OF THE TELEPHONE.

ALTHOUGH Bell's discovery of the telephone only dates back to the year 1876, it would require several volumes to describe all the applications which it has already received in so short a space of time.

We shall select, amongst the applications of the telephone, some of the most important or most interesting, and feel justified in assigning the front rank to telephonic communications.

TELEPHONIC COMMUNICATIONS.

This application of the telephone, as it is the most natural, so it is also the most advanced; but, despite the great future which must be in store for it, we must guard against the exaggerations which have found their way into print since the invention of the instrument.

A complete revolution of the whole telegraph system had been anticipated, but this anticipation was not fulfilled for two very good reasons. First of all, the telephone does not preserve a trace of the messages sent; and secondly, its rapidity in sending messages cannot be compared with that of improved telegraphs, which can produce as many as 8000 words per hour with a single wire.

The telephone, however, presents the immense advantage that it can be used without any previous special training; it is used in public buildings, in mines, submarine works, the navy, the army, etc.

The telephone does not represent, any more than any other apparatus, the universal panacea destined to cure all evils. It ought to be used in all cases where it can render good service, and not applied where it can but incompletely fulfil its functions.

Telephonic Communications in Towns.—The system of telephonic communications which has been introduced or is on the point of being introduced in all large towns of the Old and New World, requires a central office in correspondence with all the subscribers.

The central office has to reply to the calls made by the subscribers, and to place them into correspondence with any one of the other subscribers. The advantages of this combination are clear: each new subscriber constitutes for all the others a new correspondent, which daily increases the importance and usefulness of the system. Without entering into general considerations, which will suggest themselves to the reader, we will select a few examples of telephonic communications, and give a description of a central telephone office.

In the large hall of this central office (Fig. 150) we see a number of switchmen busy establishing communication between the subscribers. Here is a switchman corresponding with one of the subscribers who has called (Fig. 151). In Fig. 152 we see another *employé* replacing the warning signal.

In town, at the subscriber's office, we see the office telephone (Fig. 153), in the form generally used in houses. This

Fig. 150.—Interior of a central telephone office.

form is very convenient for business, for it enables the correspondent to speak into the mouthpiece on the left, to listen with the telephone which he takes from the hook to apply to his ear, and at the same time take notes on the desk with his right hand, which remains free.

Before following the series of operations which constitute

Fig. 151.—Switchman corresponding with a subscriber.

a complete call, let us cast a rapid glance over the system of telephones employed at the central office.

This system belongs to the class of battery telephones which are employed because the battery can be used at the same time for the ordinary electrical signal bell, as shown on the desk of Fig. 153.

Transmitter.—The transmitter is Edison's carbon telephone, described on p. 331. The circuit is formed by the battery—two Leclanchés; the transmitter is a small Ruhmkorff coil without a hammer. It forms the primary circuit of the coil. The line and the receiver of the distant station are connected with the secondary wire of the coil, the other

Fig. 152.—Switchman replacing the warning signal.

extremity of this wire is connected with the receiver of the station and with the earth.

Receiver.—The receiver is Phelps' telephone, similar to Bell's, but with a ring-shaped magnet, which makes it very convenient for handling (Fig. 153). In the position of rest, the telephone is suspended on the hook, and thereby throws

a piece forming a commutator into a swinging motion, which withdraws the telephone from the circuit, only interpolating the electric bell. On taking the telephone into the hand, the piece begins to swing again, and automatically replaces the telephone into the circuit.

The telephones of the central station, speaker and receiver, are similar to those of the subscribers; but in order to facili-

Fig. 153.—Telephone at subscriber's office.

tate the handling of these apparatus, the speaker and receiver are mounted on the same steel rod slightly curved, which serves as a handle, as represented in Fig. 151, and forms at the same time the magnet of the receiver. And now we can follow the whole series of operations.

Let us suppose that subscriber 731, whom we will call

Brown, wishes to communicate with subscriber 511, whom we will call Robinson. Brown begins by pressing on a small button at the right of the desk (Fig. 153). The telephone being suspended, the current of Brown's battery traverses the line and a small electro-magnet placed at the central station; the electro-magnet becomes active, and detaches a small wicket, which on falling makes sufficient noise to attract the attention of the switchman, and exhibits number 731. The switchman thereupon places himself in communication with Brown, by placing the wire connected with his telephone on a longitudinal copper bar which is likewise connected with Brown's line. The conversation now commences with the shout, "Halloa! halloa!"

Brown asks the switchman to put him in communication with No. 511. If No. 511 is disengaged at that moment, the switchman presses on a button after having connected the wire of No. 511 with it. Robinson's electric bell begins to ring, and when he is ready for correspondence, he presses the button of his electric bell, which causes the wicket corresponding to his number to fall. A direct connecting wire is then placed between the two horizontal bars connected with Brown's and Robinson's wires, and the communication between the two is established. If at this moment the switchman withdraws his telephone from the circuit, the conversation becomes private. If during the time of Brown and Robinson's conversation, No. 42, whom we will call Jones, wishes to correspond with Robinson, for instance, the switchman can interrupt the conversation, as a servant would in announcing a visitor.

The switchman calls Robinson, who can reply immediately or send word to Jones how soon he will be disengaged. If Brown and Robinson do not object to Jones taking part in

their conversation, the switchman is ordered to establish communication between these three persons. This is equivalent to saying "Come in," on hearing a knock at the door.

Telephonic communications thus conceived and utilized can render the greatest services, for they establish a sort of real presence, independent of any distance, between the correspondents, who can hear each other as if they were together in the same room, although often separated by considerable distances. A few other very ingenious details must be mentioned.

When the conversation between Brown and Robinson is finished, they both put back their telephones on the hooks, and press their buttons, whereupon the number of each of them is exhibited again at the central office. The switchman now knows that the conversation of the two is finished; he shuts the wicket, suppresses the direct communication between Brown and Robinson, and everything is ready for a new call.

At stations with a large number, say 500 or 600 subscribers, the numbers are arranged in order in frames of fifty to 100 wickets in each row. Special arrangements must then be made to connect the rows with each other.

The central office at New York exchanges at least 1000 communications daily, and all the arrangements are carried out to the greatest satisfaction of the subscribers. The telephone has become for them as indispensable as the omnibuses for the Londoners.

In Paris, two separate companies have been carrying on the telephonic communications, much to the detriment of subscribers and the development of the system. A fusion of the two companies has been effected lately, and since

that time matters have considerably improved. One of the companies employed Edison's system, under almost identical conditions with those we have described; the other originally employed Gower's magnetic telephone and Ader's alarum, but all magnetic telephones have recently been more or less replaced by battery telephones, which give much more satisfactory results.

There are several companies working different systems in England; but there is every probability that Government will, before long, buy up all these companies, as was done with the telegraph, and there can be no doubt that a uniform system of working, together with a uniform charge, would confer a great benefit upon the general public.

As regards the lines, they are either air or underground lines. Each of these systems has its advantages and its drawbacks. Air lines have the advantage of diminishing the injurious effects of reciprocal induction of the wires upon each other, but they involve an enormous loss of power, and are sure to become, if their number increases too much, a permanent source of danger. Of the underground wires, which are more easily worked, a large number must be joined into a comparatively thin cable, in order not to interfere with drainage pipes. The effects of induction are then very intense, and sometimes render communication difficult.

The employment of a return wire—that is to say, of an entirely metallic circuit—diminishes these inconveniences, but increases the original outlay.

At the outset, Gower's magnetic telephones were adopted in Paris, and Ader invented a most ingenious apparatus for the release of a signal at the central station, under the action of the electro-magnetic currents of Gower's telephone. Lately, electro-magnetic systems have been

abandoned, because battery transmitters give incomparably better results.

Theatrical Performances repeated by the Telephone.—Nothing could more forcibly illustrate the power and sensitiveness of telephonic communications than the repetition of theatrical performances at the recent Paris Electrical Exhibition. The performances at the Opéra, Opéra Comique, and Théatre Français could be distinctly heard in a room set apart for this purpose. Not only the voices of the actors and actresses, the songs and the orchestra, but all the incidents of the performance, the applause and laughter of the audience, and in some cases, alas! the voice of the prompter too, were faithfully repeated and listened to with intense pleasure by a never-tiring crowd of visitors.

In London, too, the operetta *La Mascotte*, was quite recently telephonically repeated before a dinner-party assembled at a restaurant at a considerable distance from the Comedy Theatre, where it was performed.

Domestic Telephones.—The telephone can be applied to a number of domestic purposes, of which we will mention a few. In many-storied houses telephonic communication with the servants will be very much appreciated. A manufacturer can correspond from his office with the manager of his works, a business man from his house with his office, a newspaper editor with the printing-office, etc.

For all these applications, when the distances are not too great, which is generally the case, magnetic telephones are the simplest, with the addition of an electric bell worked by a few Leclanchés. Gower's telephone can also be used in certain cases when the rooms where the call is to be heard are not too noisy and are always occupied, as, for instance, an office.

Telephone Stations with Electro-Magnetic Bells. — In America, electro-magnetic bells, which require no battery, are used with Bell's telephone; all that is required is to turn a winch-handle, to generate in an apparatus, similar to Clark's machine, electro-magnetic currents strong enough to work an electric bell at the receiving station.

Perrodon has constructed a very practical telephonic alarum for military purposes, in which the current of a small portative battery sent along the line throws the plate of a telephone at the opposite station into vibrations; a small hammer, similar to the hammer of a bell, produces intermittent currents.

Trouvé has modified the apparatus by making the hammer independent of the telephone, and placing it in the handle itself.

Siemens and Ducretet employ, as signals of their telephones, a small vibrating reed similar to Gower's.

Applications of the Telephone and Microphone to Medicine and to Scientific Research.

An instrument of such marvellous sensitiveness as the telephone was bound to find, and has actually found, several applications in medicine and physiology.

We will only mention here Ducretet's stethoscopic microphone and Boudet's microphone.

Ducretet's Stethoscopic Microphone.—We mention this apparatus first, because it is the first apparatus of the kind constructed. With it the observer can hear in several telephones at the same time the faintest pulsations, beating of the heart, of the pulse, and the arteries.

This apparatus is very sensitive; its great sensitiveness is, perhaps, a defect.

Two of Marey's drums are joined to the microphone (Fig. 154). The one T′ acts as sounder, the other T as receiver. The faintest motion communicated to the drum T acts, by the intermedium of the connecting indiarubber

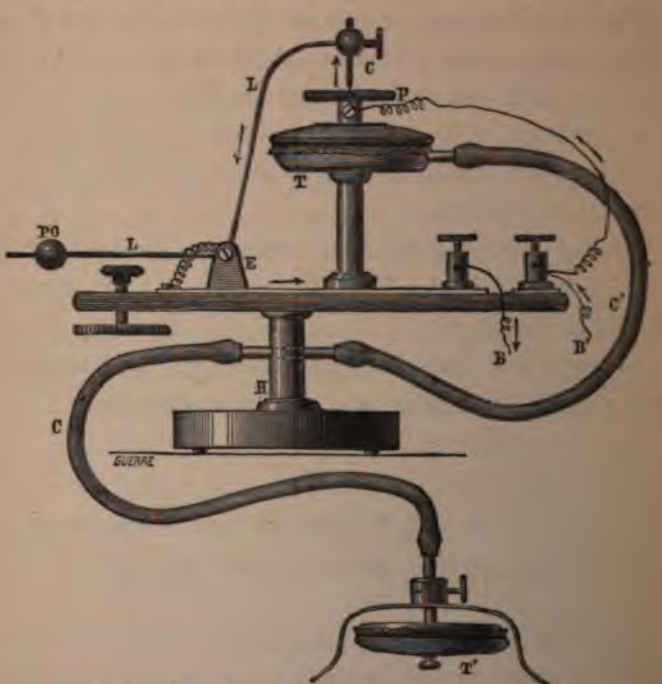


Fig. 154.—Ducretet's stethoscopic microphone.

tube C C′, on the drum T′, and consequently on the micro-
ıone. This microphone is connected with a lever L,
ınted in E, whose sensitiveness can be regulated by the
ınterpoise P O. It terminates in a pencil C of gas carbon
r graphite, which rests on a plate P of the same substance,
fixed on the receiving drum. The whole forms a complete
circuit, containing a battery of one to three Daniells or

Leclanchés, and the telephones for hearing the beatings of the sounding-drum T′; B and B′ are conducting wires.

This microphone is capable of modifications; it marks an undoubted progress in physiological science. By substituting a small mouthpiece for the drum T, it can be used for transmission of speech.

Boudet's Microphone applied to Medicine.—A small and slightly concave plate of hardened indiarubber, five centi-

Fig. 155.—Dr. Boudet's microphone.

metres by two, with a round hole in its centre, forms the stand of the apparatus (Fig. 155). At one of its extremities stands a vertical rod A about three centimetres high, along which a very small copper waggon I is made to slide up and down by means of a regulating screw V; a carbon cylinder D, one centimetre and a half long and five millimetres thick, oscillates on a transversal axis between the uprights of the waggon. A small horizontal spring E, one end of which is

fixed to the opposite extremity of the caoutchouc plate, abuts with its free end H against the carbon cylinder. This spring carries a small fragment of carbon, which touches the extremity of the oscillating carbon cylinder. Finally, underneath the first spring and parallel to it, as in Marey's sphygmograph, is another spring F terminating in a sounding-button K, which passes through the hole of the plate.

The least pressure exercised on the button is transmitted, by means of the springs F and E, to the two carbon contacts, and causes a variation of intensity in the passing current. These variations are received by a telephone, which the observer applies to his ear. The mobility of the two carbons will account for the extreme sensitiveness of this microphone.

It is, however, necessary in these experiments to obtain a certain amount of initial pressure. This can partly be obtained by means of the regulating screw, which can press the oscillating carbon cylinder more or less close against the lower carbon. But this is not sufficient, for, on feeling a rather quick pulse, the motions communicated to the springs would suddenly raise the upper carbon and cause a breaking of the current.

Boudet has obviated this inconvenience by placing in the waggon, above one extremity of the oscillating cylinder, a small piece of paper bent in form of a V, which acts as a spring. The addition of this spring presents several advantages. Paper is a body of very feeble but at the same time very perfect elasticity, as has been proved by Savard's experiments. It lends itself, consequently, much more readily than steel and caoutchouc to the successive interruptions and approaches of the carbon contacts, or rather to the variations of their reciprocal pressure. The

apparatus thus constructed, when applied to an artery, indicates all the murmurs that take place inside the vessel, and with a little practice the observer can easily distinguish differences of rhythm, the breath-sounds, etc. The pulsation is very strongly accentuated, the normal dicrotism becomes perceptible; in one word, the tracings of the pulse are heard, such as they are registered by the sphygmograph. Applied to a muscle, the same instrument becomes an excellent myophone. It indicates the normal muscular sound, and when contraction takes place, the characteristic rumbling noise of this phenomenon is distinctly heard.

Chardin and Prayer have also constructed a sounding micro-telephone for sounding wounds. We refer our readers to No. 312 of *La Nature* (May 21, 1879), where this apparatus is described.

Scientific Applications of the Telephone.—We cannot describe in this book all the scientific applications of the telephone and microphone, and the immense services these two instruments have already rendered. We will quote, amongst a very large number, Hughes' induction balance.

Hughes' Induction-Current Balance.[1]—"Immediately upon the announcement of Arago's discovery of the influence of rotating plates of metal upon a magnetic needle (1824), and Faraday's important discovery of voltaic and magnetic induction (1830), it became evident that the induced currents circulating in a metallic mass might be so acted upon either by voltaic or induced currents as to bring some new light to bear on the molecular construction of metallic bodies.

[1] This instrument is so interesting, both as regards its construction and also its practical application, that I give here an account of it, taken from *Nature*, 1880, in the inventor's own words, although in the original only its name is mentioned.—(The translator.)

"The question was particularly studied by Babbage, Sir John Herschell, and by Dové, who constructed an induction balance wherein two separate induction coils, each having its primary and secondary coils, were joined together in such a manner that the induced current in one coil was made to neutralize the induced current in the opposite coil, thus forming an induction balance, to which he gave the name of differential inductor. In those days physicists did not possess the exquisitely sensitive galvanometers and other means of research that we possess to-day; but sufficiently important results were obtained to prove that a vast field of research would be opened if a perfect induction balance could be found, together with the means of correctly estimating the results obtained. In experimenting with the microphone, I had ample occasion to appreciate the exquisite sensitiveness of the telephone to minute induced currents. This led me to study the question of induction by aid of the telephone and microphone.

"Continuing this line of inquiry, I thought I might again attempt to investigate the molecular construction of metals and alloys, and with this object, I have obtained, after numerous comparative failures, a perfect induction balance which is not only exquisitely sensitive and exact, but allows us to obtain direct comparative measures of the force or disturbance produced by the induction of any metal or conductor.

"The instrument consists (1) of the new induction-current balance; (2) a microphone with a clock as a source of sound; (3) an electric sonometer, or absolute sound-measurer—a late invention of my own; (4) a receiving telephone and three elements of Daniell's battery.

"In order to have a perfect induction-current balance

suitable for physical research, all its coils, as well as the size and amount of wire, should be equal. The primary and secondary coils should be separate, and not superposed. The exterior diameter of the coils is five centimetres and a half, having an interior vacant circular space of three centimetres and a half, the depth of this flat coil or spool is seven millimetres.

"Upon this boxwood spool are wound a hundred metres of No. 32 silk-covered copper wire. I use four of such coils, formed into two pairs, the secondary coil being fixed permanently, or by means of an adjustable slide at a distance of five millimetres from its primary; on the second similar pair there is a fine micrometer screw, allowing me to adjust the balance to the degree of perfection required.

"These two pairs of coils should be placed at a distance not less than one metre from each other, so that no disturbing cause should exist from their proximity. The two primary coils are joined in series to the battery, the circuit also passing through the microphone.

"The telephone is well adapted as an indicator, but not as a measurer of the force of rapid induced currents. For this reason, I have joined to this instrument an instrument to which I have given the name of electric sonometer. This consists of three coils similar to those already described, two of which are placed horizontally at a fixed distance of forty centimetres apart, and the communication with the battery is so arranged that there are similar but opposing poles in each coil; between these there is a coil which can move on a marked sliding scale divided into millimetres; in a line with these two opposing primary coils, the centre coil is the secondary one, and connected by means of a circuit-changing key with the telephone in place of the induction

balance. If this secondary coil is near either primary coil, we hear loud tones, due to its proximity. The same effect takes place if the secondary coil is near the opposing coil, except that the induced current is now in a contrary direction, as a similar pole of the primary acts now on the opposite side of the induction coil; the consequence is that as we withdraw it from one coil approaching the other, we must pass a line of absolute zero, where no current whatever can be induced, owing to the absolute equal forces acting equally on both sides of the induction coil. This point is in the exact centre between the two coils, no matter how near or distant they may be. We thus possess a sonometer having an absolute zero of sound; each degree that it is moved is accompanied by its relative degree of increase, and this measure may be expressed in the degree of the millimetres passed through, or by the square of the distances in accordance with the curve of electro-magnetic action.

"If we place in the coils of the induction balance a piece of metal—say copper, bismuth, or iron—we at once produce a disturbance of the balance, and it will give out sounds more or less intense on the telephone according to the mass, or, if of similar sizes, according to the molecular structure of the metal. The volume and intensity of the sound is invariably the same for a similar metal. If by means of the switching key the telephone is instantly transferred to the sonometer, and if its coil be at zero, we should hear sounds when the key is up or in connection with the induction balance, and no sounds, or silence, when the key is down or in connection with the sonometer. If the sonometer coil was moved through several degrees, or through more than the required amount, we should find

that the sounds increase when the key is depressed; but when the coil is moved to a degree where there is absolute equality, if the key is up or down, then the degree on scale should give the true value of the disturbance created in the induction balance; and this is so exact that if we put, say a silver coin whose value is 115°, no other degree will produce equality. Once knowing, therefore, the value of any metal or alloy, it is not necessary to know in advance what the metal is, for if its equality is 115°, it is a silver coin; if 52°, iron; if 40°, lead; if 10°, bismuth; and as there is a very wide limit between each metal, the reading of the value of each is very rapid, a few seconds sufficing to give the exact sound-value of any metal or alloy.

"The instrument gives very different values for different metals or alloys; consequently, we cannot obtain a balance by employing two discs of different metals, and the instrument is so sensitive to any variation in mass or matter, that it instantly detects the difference by clear loud tones on the telephone. If we place two gold sovereigns of equal weight and value, one in each coil, there is complete silence, indicating identity or equality between them. But if one of them is a false sovereign, or even gold of a different alloy, the fact is instantly detected by the electrical balance being disturbed. The instrument thus becomes a rapid and perfect coin-detector, and can test any alloy, giving instantly its electrical value. It also measures the electrical resistances of wires or fluids. In order to make it do this, we have only to place the resistance to be measured across the two wires of one induction coil and on the other, known resistance units. In this way we can produce a perfect balance, for it then becomes an induction bridge, the result

and modes of testing of which are somewhat similar to Wheatstone's bridge.

"It measures also the electro-static capacity of Leyden jars or condensers, and is sufficiently sensitive to appreciate and measure a surface of tinfoil not larger than four inches square, the condenser being simply placed between the wires of one pair of coils, and the disturbance produced being measured on the sonometer."

Carlo Resio has applied the telephone to the measurement of the torsion of the axles of machines in motion, and has invented a very interesting method for measuring the work expended or produced by a telephonic equilibrium. All the details of this interesting application will be found in *La Lumière Électrique* of the 15th of March, 1880.

The Telephone applied to the Indication of Electric Currents of very Feeble Intensity.—The following is D'Arsonval's own account of this interesting application:—

"It is clear that the telephone can only indicate the variations of an electric current, however feeble they may be; but I have, with the help of this instrument, found the means of indicating the presence of a continuous current, however feeble it may be. I have succeeded in doing this by a very simple method. I pass the supposed current into the telephone, and, in order to obtain variations, mechanically interrupt this current by a diapason. If the telephone is not traversed by any current, the instrument remains mute. If, on the contrary, the feeblest current exists, the telephone vibrates in unison with the diapason."

Various Applications of the Telephone.—The applications which the telephone has already found are innumerable: several volumes like this would not be sufficient to describe them all. Hughes' audiometer or sonometer, the induction

balance, the measurement of resistances, Warren de la Rue's researches on the electric discharge of high-tension batteries, —these are the principal scientific applications of the telephone.

Telephonic communications in mines, workshops, and factories, the measurement of torsion in the axles of machines in motion, the analysis of metals by the induction balance, constitute the principal industrial applications.

Every day witnesses new experiments, new problems for the solution of which the telephone affords a means of investigation, a valuable help.

In other cases new difficulties arise from its application, but science as well as these applications profit by the researches rendered necessary to overcome these difficulties. Of this we will quote an example. When networks of telephone wires were established in the sewers, there arose, through the forced close proximity of the wires, a difficulty of so serious a character as to jeopardize the development of the system. It was a question of reciprocal induction of the different wires, producing a very Babel of conversations, and a noise which would render conversation very difficult, if not altogether impossible. If, on the other hand, telephone wires run side by side with telegraph wires, and the lines are widely spread, the emission of successive signals produces on the telephone wires sounds which closely resemble the crackling noise heard when using a frying-pan.

Of all the suggestions made for getting over this difficulty, the employment of a double wire has proved the only effective one up to the present, but it is to be hoped that some more economical solution will give the same results.

This example will show how many technical and scien-

tific questions of the greatest interest have been raised by the practical applications of the telephone, notwithstanding the recent date of its invention—only six years ago.

The rapid development of the telephone since its discovery is unique in the annals of science; it shows the increasing importance of science for the progress of civilisation and also the immense import of Professor Graham Bell's discovery.

PART IV.

VARIOUS APPLICATIONS OF ELECTRICITY.

Liveing's Apparatus for indicating the Quantity of Fire-Damp in Coal-Mines.—It is well known that, in order to avert the dangers of an explosion in coal-mines, no burning substance must come in contact with the ambient air of the mine.

Davy's lamp and its different modifications, and quite recently the introduction of incandescent electric lamps, have partly solved this problem; but even with these precautions, a thoughtless act of the miner in any part of the working containing the explosive mixture of marsh gas and air, can cause a serious accident. It is therefore of the utmost importance to receive an immediate warning at the moment when the air begins to contain a dangerous proportion of hydro-carbon, so as to be able, by active ventilation, to avoid the danger of explosion.

The lengthening of the flame of a Davy lamp first served as a warning in this case; other apparatus have been constructed since with the object of obtaining more accurate indications, and even of ascertaining the quantity of explosive gas in the air. These apparatus can be divided into two classes—those founded on the physical properties

of the gaseous mixture, and those founded on its chemical properties. The former are represented by Forbes' and Ansell's apparatus, but, as electricity has no part whatever in their working, they do not come within the scope of this book. The latter comprise the apparatus of Coquillon, Angus Smith, Liveing, Monnier, and Somzée. All these, with the exception of Angus Smith's apparatus, are founded on the use of electricity, and three of them—Liveing's, Monnier's, and Somzée's—were exhibited at the Paris Electrical Exhibition.

The principle of Liveing's apparatus is the following:—

A mixture of air and marsh gas containing less than five per cent. in volume of the latter gas, is not explosive. If, however, such a mixture comes in contact with a platinum wire which has been raised to a sufficiently high temperature, it will, by a phenomenon of condensation or perhaps of local combustion, raise the temperature of this platinum wire, and the more so the more marsh gas the mixture contains. If, therefore, we raise two platinum wires to the same temperature, and place the one in the air of the mine, and the other in an atmosphere free from hydro-carbon, the temperature of the former will rise in proportion to the quantity of hydro-carbon contained in the mine. The intensity of light of the platinum wire will increase with the temperature, and, by comparing this intensity with that of the other wire, we shall be able to determine the quantity of fire-damp in the mine.

The apparatus employed for this purpose is represented in section in Fig. 156, and in perspective in Fig. 157. It consists of a narrow wooden box A B about twenty centimetres in length; a glass plate C forms part of its cover, which is perforated by two tubes D and E for the admission

and the outlet of the gas. At the two extremities of the box—at F and G—are two platinum spirals contained in the same circuit through which an electric current can be passed at the same time by means of a small magneto-electric machine enclosed in the lower part of the box. One of the spirals G is enclosed in a glass tube fixed to a sort of stopper N. This tube contains ordinary air without any admixture of fire-damp. The other spiral in enclosed in a tube fixed to a similar stopper M, but which is only partly of glass at the end, the lower part being formed of

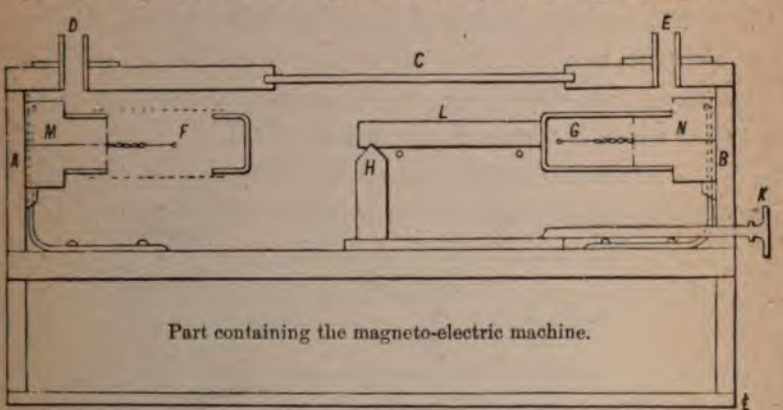


Fig. 156.—Section of Liveing's apparatus.

metallic wire gauze, so that this tube is full of air having the same composition as the air of the box and consequently of the mine. When the current passes through the spirals, these spirals are, as long as the air contains no fire-damp, heated to the same degree, and have therefore the same luminous intensity; but as soon as the air contains any hydro-carbon, the spiral F becomes more brilliant, and its luminous intensity enables us, as we have said, to determine the proportion of fire-damp. This determination is made by means of a small photometer

contained in the box. A square piece of wood, placed at an equal distance from the two spirals, is bevelled off at its upper end so as to present an inclined surface to the light of each spiral. These two surfaces are covered with white paper and their luminous intensity can easily be compared by looking through the glass C. By means of the screw K the rod H can be moved until the luminous intensity on both inclined surfaces is equal. A graduated scale L indicates the proportion of fire-damp corresponding to each position of H.

The scale is graduated experimentally, by introducing into the box mixtures of known quantities of air and hydro-carbon—assuming the composition of fire-damp to be CH_4, which is correct on the whole.

The annexed table shows the differences of intensity corresponding to different quantities of CH_4—

Quantity of CH_4.	Relative illuminating power of the spirals.	
	Covered spiral.	Open spiral.
Pure air	1	1·0
¼ per cent. of CH_4	1	1·24
½ " "	1	1·65
1 " "	1	2·78
2 " "	1	5·1
3 " "	1	22·0
4 " "	1	64·0

The table shows the sensitiveness of the apparatus for quantities of inflammable gas exceeding two per cent.

Fig. 157 represents the exterior view of the apparatus. The magneto-electric machine, which is a sort of Siemens' machine with permanent magnets, is enclosed in the lower

protruding part of the box, which contains the tubes and the photometer. The box can easily be held in the left hand by pressing it against the chest, or in a recumbent position against the knees. At the same time, the handle is turned with the right hand and the photometer is observed. If there is a difference in the intensity of the two white surfaces, the observer ceases turning the handle, and slightly moves H by pulling K; then he begins turning again, and so on, until a uniform tint is obtained. The only thing to be done now is to read off the scale.

To introduce the air of the mine into the box, it is

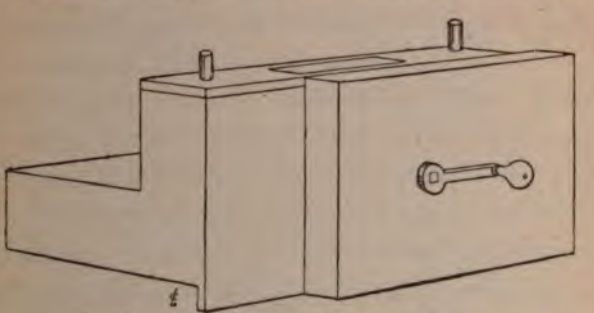


Fig. 157.—Exterior view of Liveing's apparatus.

sufficient to remove the cover of the box for a few minutes; but when a particular mixture—the air contained in some fissure, for instance—has to be examined, indiarubber tubes are fixed to the openings E and D (Fig. 156), one of the tubes is introduced into the cavity, and the gas contained in the cavity sucked through the apparatus with the month.

The platinum spirals are mounted in such a way that they can easily be replaced; the wooden stoppers M and N which support them are provided with contacts which press against a spring placed at each extremity of the box. These contacts have the double function of establishing

communication and keeping the pieces M and N in their place.

It will be seen that the apparatus is very portable, and can easily be entrusted to a workman who has to take observations in different parts of a mine.

Somzée's Apparatus for indicating the Quantity of Fire-Damp in Coal-Mines.—Somzée has constructed a number of apparatus for indicating the presence of marsh gas in coal-mines, some of which do not require the help of electricity, and consequently do not come within the scope of this book. The most practical of his apparatus exhibited at the Paris Electrical Exhibition were the following :—

1. When a Davy lamp burns in an atmosphere containing a certain proportion of marsh gas, its flame is elongated, and at the same time acquires a much higher calorific power. A fixed point situated at a certain distance from the top of the flame will, therefore, when the atmosphere contains hydro-carbon, be raised to a much higher temperature, and this rise of temperature can be utilized to produce the closing of a circuit and to give an electric signal.

Fig. 158 shows a practical application of this principle. Externally the apparatus resembles an ordinary Davy lamp, but the socket contains, besides the lamp, a small Marié Davy battery and clockwork R. The current, after having traversed the clockwork, arrives on the one hand at the plate L, on the other at the screw G. Between the chimney C and the metallic wire gauze at A is an expansion apparatus formed of a flat zinc tube bent in the shape of a reversed U. One of the branches of this U is filled with zinc filings, the other is empty. As long as the flame burns in a normal atmosphere, the heat produced does not sensibly

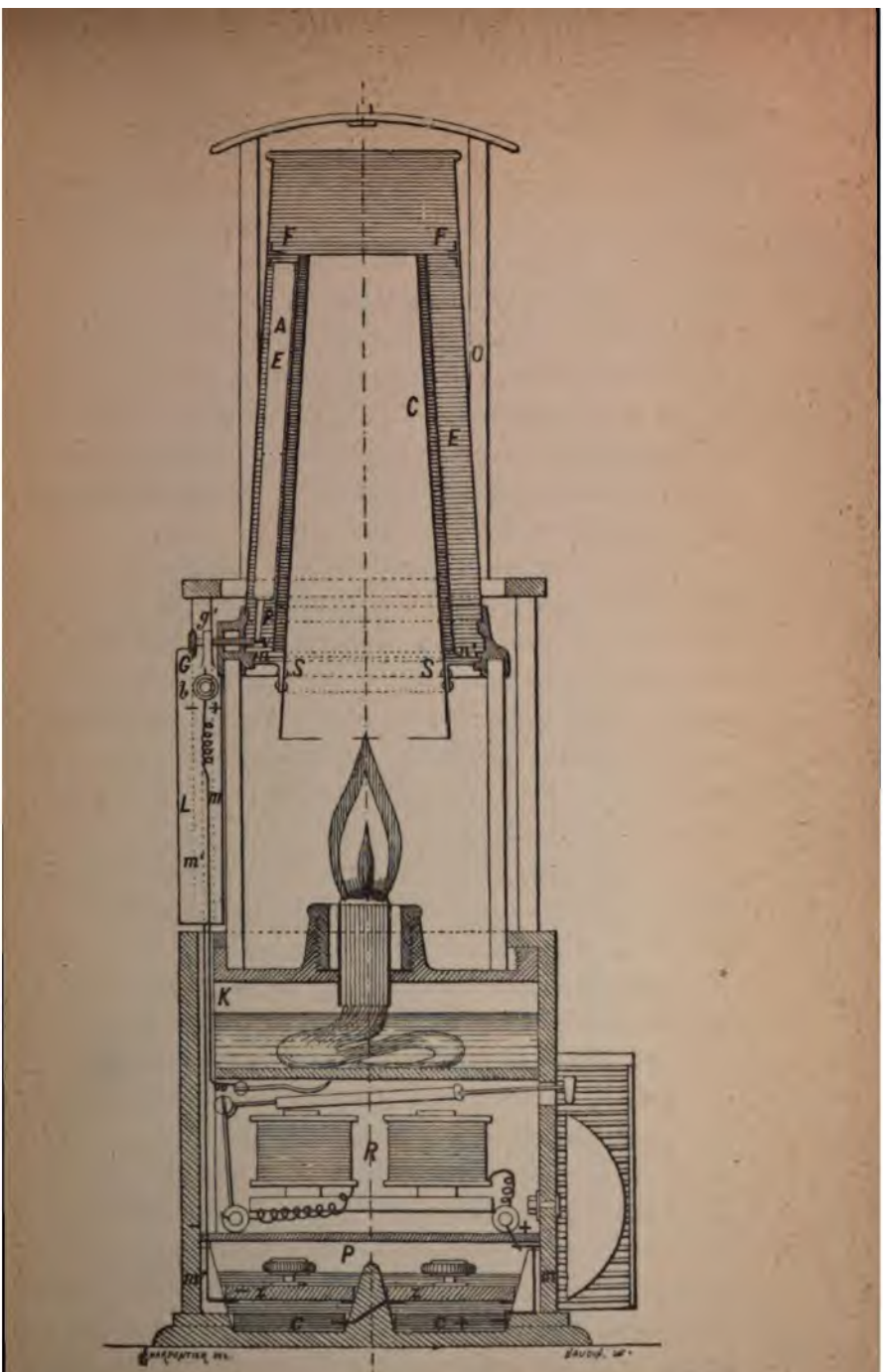


Fig. 158.—Somzée's apparatus (1) for indicating the presence of fire-damp in coal-mines.

affect this apparatus; but as soon as the air is charged with 1/5th to 1/4th of fire-damp, the flame is lengthened and fills the cylinder of the lamp. The expansion apparatus is then acted on, the empty tube expands more than the full one, and, as it cannot expand in length, it pushes the whole of the mass towards the contact point *p*, which closes the circuit of the clockwork. The signal is given, and as the mixture only becomes explosive for twice the quantity of marsh gas, there is plenty of time for ventilating and renewing the air of the mine.

Bonnée employs various methods for protecting the expansion apparatus against the influence of the flame during normal combustion. In some cases calorific isolation is produced by surrounding the whole of the chimney with metallic wire gauze; in others by a glass cylinder also surrounding the chimney, which keeps the circuit of expansion in the dark, and prevents the heat-rays from passing through the glass.

2. Another kind of apparatus is founded on the different absorption of calorific rays by different gases. Two tubes T T_1 (Fig. 159), closed at both ends by thick plates S S', and similar in other respects to those employed by Tyndall for his experiments, receive, by the aid of a mirror, the rays of the same source F. This source is nothing but an ordinary miner's lamp. One of the tubes T is full of normal air, the other T_1 is continually traversed by the air of the mine. The rays, after having traversed the two tubes, fall upon the two opposite faces of a Melloni's thermo-electric pile P, in connection with a galvanometer G. As long as the air is the same in both tubes, the galvanometer remains at zero, but as soon as the composition of the air in the two tubes is different, the tube containing the normal

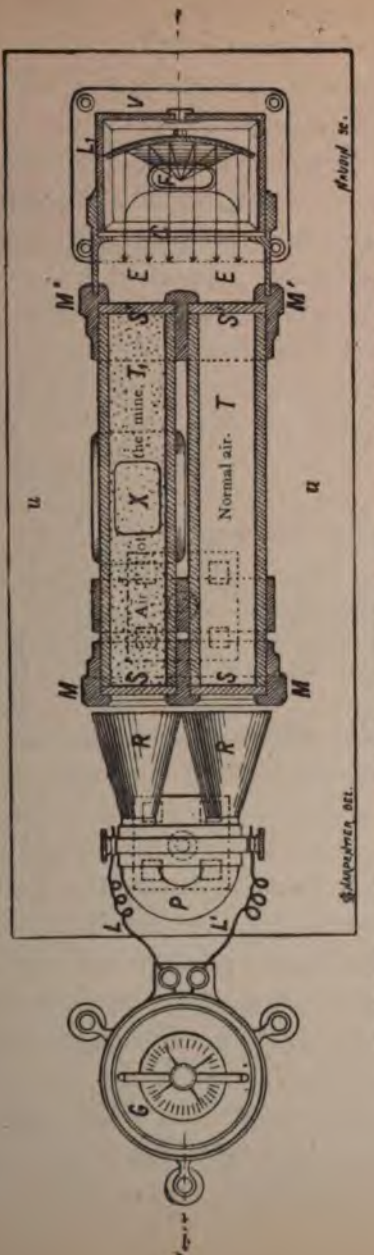


Fig. 159.—Somzée's apparatus (2) for indicating the presence of fire-damp in coal-mines.

air allows the heat-rays to pass entirely, on account of the diathermancy of air for these rays, whilst the other tube, containing marsh gas, absorbs part of the heat-rays, and this absorption is proportionate to the quantity of explosive gas in the atmosphere. The result is a difference of temperature between the two faces of the pile, and consequently a deflection of the galvanometer, which indicates the quantity of fire-damp contained in the air.

This apparatus is very sensitive, but it is not portable. It can, however, be set up at a given point, and receive successively, by means of tubes, the air from different parts of the mine.

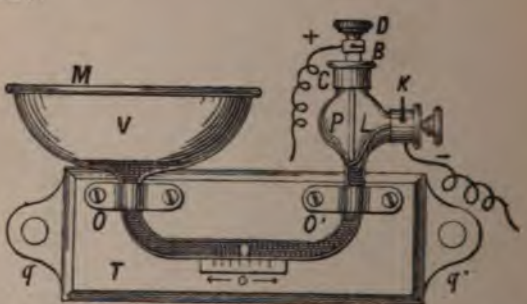


Fig. 160.—Somzée's apparatus (3) for indicating the presence of fire-damp in coal-mines.

3. The third class of apparatus is based on the diffusion of gas through a porous medium. It is a well-known fact that the lighter a gas the greater its diffusive power. Marsh gas will therefore pass through a porous membrane much more quickly than atmospheric air. The apparatus represented in Fig. 160 is constructed on this principle. It consists of two vessels communicating by means of the tube O O'. When the air contains a certain quantity of marsh gas, it penetrates through the porous plate M of the vessel V much more quickly than the air contained in the vessel

can pass out; the pressure produced thereby in the vessel V acts upon the mercury contained in the tube of communication O O'. This mercury rises and establishes contact between the rod P and the spring L, and sets the bell ringing. A certain number of these apparatus can be placed in different parts of the mine, and ring either at a central station in the mine itself or at a station on the surface.

Monnier's Automatic Methanometer.—Another very ingenious, but rather complicated, apparatus for indicating and determining the quantity of hydro-carbon in coal-mines has been constructed by Denis Monnier, Professor of Chemistry at the Geneva University.

It is based upon the oxidation of marsh gas (called *méthane* in French) by an excess of atmospheric air, under the agency of a high temperature produced by an induction spark or by red-hot platinum. This decomposition is represented by the following formula:—

$$CH_4 + O_4 = CO_2 + 2H_2O.$$

The carbon dioxide formed, unlike the water vapour, is not condensed, and acts on the level of the mercury in a manometer tube. The changes of level of the mercury produced by different quantities of carbon dioxide are electrically transmitted to a dial in the office of the engineer of the mine, and also ring an alarm-bell when the percentage of marsh gas in the mine threatens an explosion.

For the details of this interesting apparatus, we refer the reader to *La Lumière Électrique* of the 19th of October, 1881.

Bright's Street Fire-Alarm and District Telegraph.—This system was exhibited at the recent Paris Electrical Exhibition, and gained for its inventor the gold medal.

It differs from all other systems hitherto invented by the manner in which it indicates, at the receiving station, the station from whence the signal emanates. The method is purely electrical, and requires neither wheels, nor springs, nor any other intricate mechanism. The principal applications exhibited at Paris consisted of a street fire-alarm employed by the London Fire Brigade, and an automatic alarm for the protection of the interior of dwellings.

Let us first examine the general working of the system in its simplest form.

At the receiving station is a battery, one of whose poles is at earth, the other being connected to one end of each coil of a differential relay. This latter is constructed in such a manner that, as often as its needle is deflected, it closes a local circuit supplied by a few of Leclanché's elements. The free end of the wire of one of the relay coils is connected with a key, and through that key with the line; when the key is pressed down, the line circuit is interrupted. The free end of the wire of the other relay coil is connected with a rheostat of a resistance equal to that of the line wire, and also with a commutator, which, under ordinary circumstances—that is to say, when no signal is sent—is connected with the earth. In this way the differential relay is balanced by the current passing, on the one hand into the line, and on the other into the rheostat.

At those points of the line (pillar-posts or mural boxes, whence the signals are to emanate), handles are fixed with the inscription, "Pull." By pulling the handle, a small coil of definite resistance is brought into circuit. This increases the electrical resistance of the wire along the streets, which had been previously balanced by a corresponding resistance

in a rheostat at the fire brigade station, and the needle of a galvanometer relay is deflected, until the commutator handle at the receiving station, on being turned, inserts an additional electrical resistance equivalent to that of the alarm-post whence the call has emanated. The locality of the post is shown on the dial of the commutator. In the interior of the pillar or of the mural box is a transmitter similar to those which are used in telegraphy, and the electro-magnet is formed by the resistance coil which has been mentioned, and which is called a localizer; this coil, of course, has a core of soft iron. In order to work this transmitter in answer to the person who has given the signal, the person in charge of the receiving station, as soon as he has ascertained from which station the call emanates, pushes the key which has been mentioned above; a rupture of the line circuit ensues, the armature of the electro-magnet is attracted, and the speaker acts.

In London, instead of a speaker, the armature carries a white disc moving over a red ground. As long as the current passes, the white disc is withdrawn and shows the red ground; when the current is broken at the receiving station, the disc is detached and covers the red ground. In this way a simple signal can be sent, or, if the calling person understand the Morse alphabet, a few sentences may be sent by exercising longer or shorter pressures on the key. On his part, this person can answer by the aid of the handle at the station. Consequently, the same wire can be employed either for a simple call within reach of an inexperienced person, or as an ordinary telegraph. It is evident that the disc or the speaker, or even both, can be used for return signals; it is also clear that ordinary telegraphic or telephonic transmitters and receivers can,

without any further modification, be added to the apparatus, in order to make it more complete and more perfect.

Another peculiarity of this system, besides the substitution of the disc for the speaker, and which is perhaps even more important, is an arrangement by means of which, instead of establishing an earth connection at each box, and only passing the current at the moment of call, the circuit remains constantly closed, and the current returns through a continuous line to the receiving station (Fig. 161). Under normal conditions, the current does not pass into the resistance coils, because it finds a shorter route; but by pulling the handle at one of the stations, the shunt is opened, and the current is obliged to pass through the coil placed at this point. This arrangement obviates the necessity of testing the apparatus or inspecting the line, for any defect announces itself by ringing the call-bell, which cannot, as in the case of a real call, be reduced to silence by turning the index of the commutator; it rings for every position of the index.

Fig. 161 is a diagram of the circuit established in the City; P is the general battery, p the local battery, and the other letters correspond to those of Fig. 162. This latter is a view of the apparatus exhibited at the Palais de l'Industrie G is the differential relay; n its needle which closes the local circuit and sets the call-bell b ringing on being deflected from one side to the other; K is the key for interrupting the current and transmitting signals to the call station, by the motions of the discs d d; R is the rheostat by means of which the circuit of the station is kept in balance with that of the line; D the dial of the commutator; t, t, t, t, are the terminals for connecting the apparatus of the station to the line of the battery. A A are call-boxes (Nos. 4 and 5

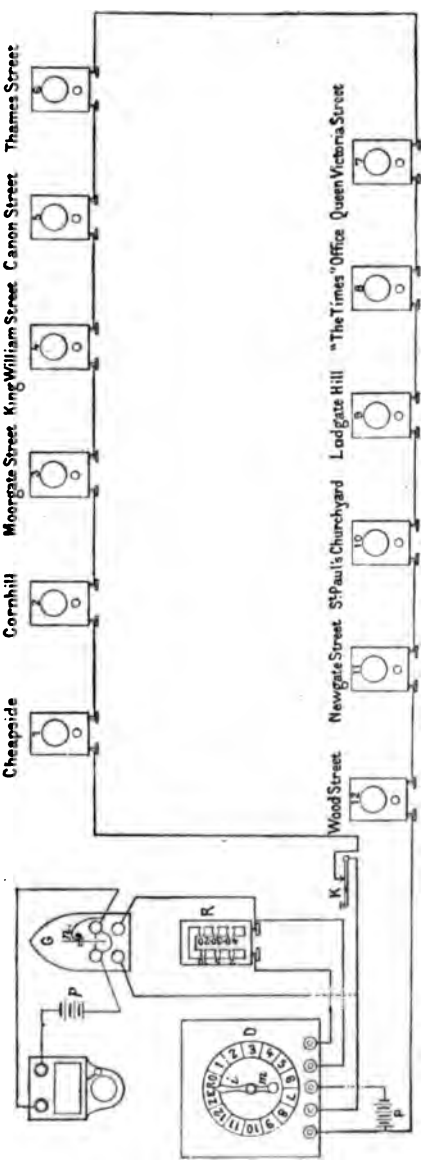


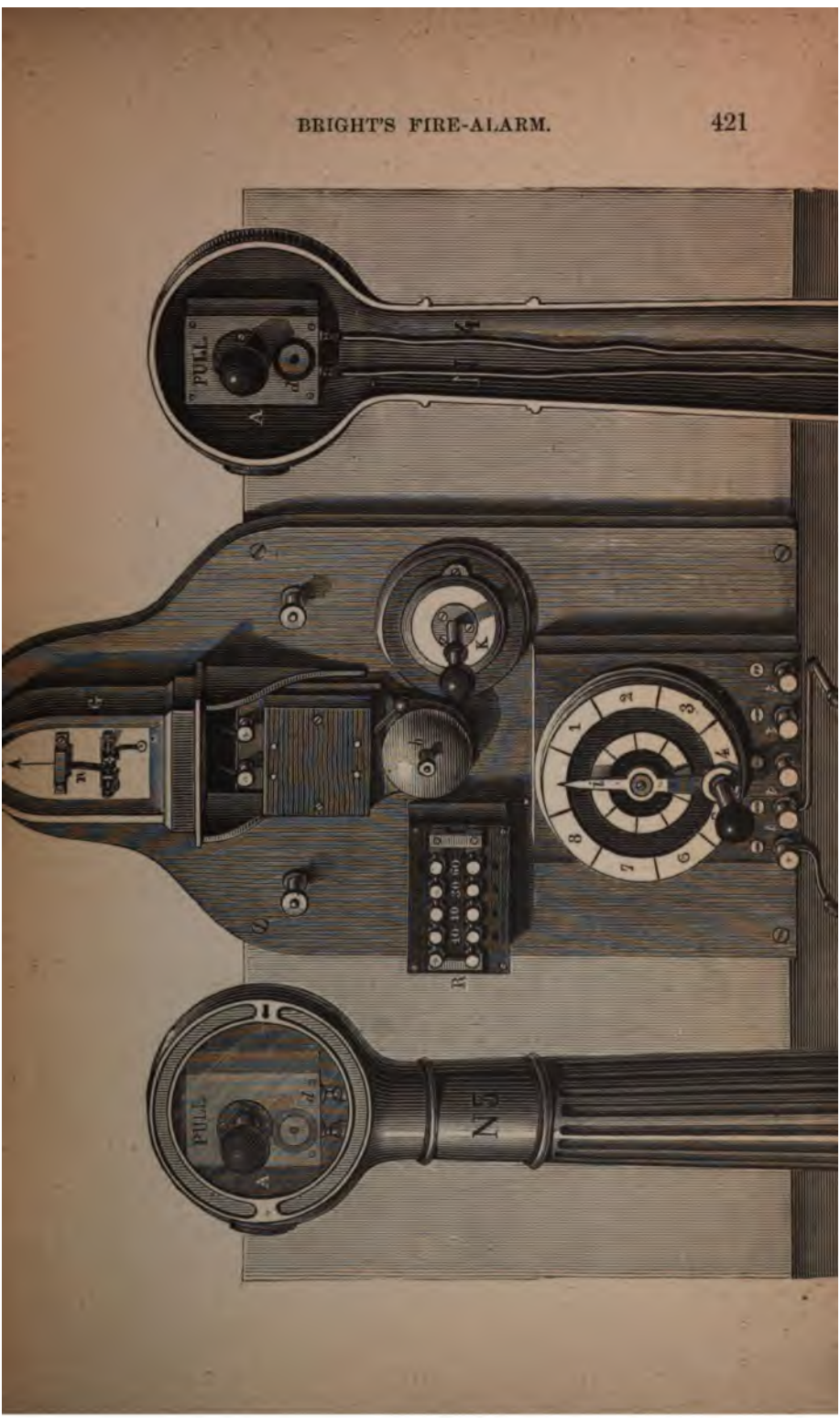
Fig. 161.—Diagram of the City stations of Bright's fire-alarm.

of the circuit) with their handles, and *d d* the discs mentioned above.

In the interior view of the call-box (Fig. 163), E E is the localizer, consisting of a resistance coil which forms an electro-magnet. A is the armature of this latter, which turns the disc, designated by K instead of *d*; L and L′ are the contact plates forming short circuit on the line,—they are separated when the handle is pulled. The wires F F′ and G G′ insert the coils into the circuit, and form connections at P and P′ with the line.

We pass now to the description of the automatic alarm for the interior of dwelling-houses and shops. Its description involves more general principles but less details than that of the foregoing apparatus. The principle of the apparatus is the combination of the preceding method with an improved bimetallic thermostat, adjustable for different temperatures by means of a screw. A section of this thermostat is represented in Fig. 164. When contact has been established by the expansion of the metallic spring, at the temperature for which it has been adjusted, the current passes into a localizer, exactly as in the case where the handle of the call-box is pulled. In this case, however, no answer is required from the receiving station, and the resistance coil has no longer the form of an electro-magnet, neither is it enclosed in a metal box, but simply in a wooden box, so as to be placed in a recess of the wall, close to the thermostat. This latter and the conducting wire attached to it can be enclosed in the wall or fixed at the top of it, and will last as long as the building itself. In houses where electric bells are already established, their wires can be used for the fire-alarm.

The same localizer can, however, as will easily be under-


PULL
PULL

stood, be introduced into the circuit, either by a thermostat or by a handle, as the case may require. When the receiving apparatus is at some private office, and not at a fire brigade

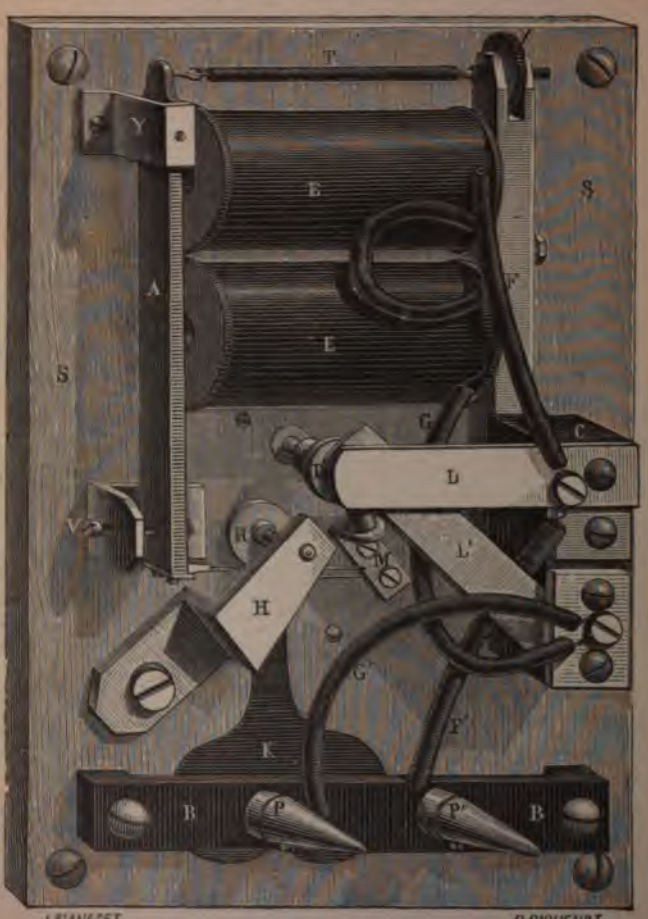


Fig. 163.—Interior view of a call-box.

station, it is advisable to set up a telephone and a handle at the spot where the thermostat is placed. In that case, if a fire breaks out during the night, or when nobody is there to

extinguish it, a warning signal is immediately transmitted to the office, and the signal can be transmitted to the nearest fire brigade station; at ordinary times the handle and the telephone can be used for business communications. The relay at the office can be arranged in such a manner that the alarm-bell rings at the same time at the office and at the fire brigade station, whilst during the day-time, the communication with the fire brigade station being broken, it only acts at the office, and serves for ordinary telephonic communications.

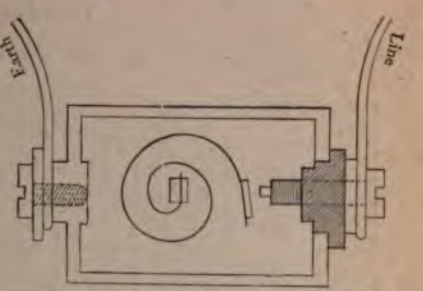


Fig. 164.—Thermostat for automatic fire-alarms in dwelling-houses and shops.

Mr. Bright has invented some combinations which make it possible to distinguish between two calls made simultaneously at two different points of the same circuit, and also for an automatic movement of the index of the commutator. But these combinations have not yet been adopted in practice. Captain Shaw, of the Metropolitan Fire Brigade, prefers an apparatus where the operator is obliged to turn the index himself, to make sure of his attention. In fact, he considers two calls made at two minutes' interval such a rare occurrence that he thinks it useless to provide for this case. On the other hand, it is very easy, by the aid of existing arrangements, to distinguish between two calls made at less than two minutes' interval.

A police telephone and signal system, on the same principle as Bright's fire-alarm, has been introduced in several large American towns.

Kelway's Electric Log.—This log provides for the continuous registration on dials placed in the captain's cabin, chart-room, engine-room, etc., showing on each the distance run. In order that the condition of the log should be known, an arrangement is made to sound an electric bell every one-eighth of a knot. The position in which the log is placed is said to obviate many inaccuracies which arise in the use of other logs. In Fig. 165, A A shows the bottom of a vessel supposed to be going in the direction indicated by the arrow B. C is a sluice-valve bolted to the bottom of the vessel, shown open, and allowing the sea full access to the iron box D. The iron box D is bolted to the upper flange of the valve C, and is closed at its top by the metal plate E, which effectually prevents the ingress of water to the ship's hold. Through the stuffing-box F in plate E passes the metal rod G, the screw-thread on which raises or lowers the metal cage H. To the bottom of cage H is affixed the cylinder I, having its opening for the passage of water in a fore-and-aft direction, or in a line with the keel of the vessel. The passage of water through I causes the screw R to rotate with the spindle L. On the spindle L is an endless screw which revolves, by the intervention of a

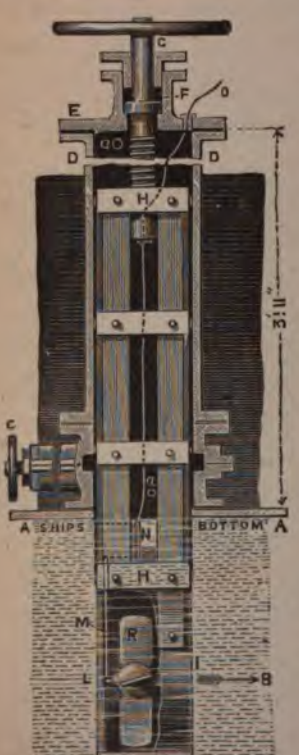


Fig. 165.—Kelway's electric log.

wheel, the vertical spindle M, which in its turn actuates a series of wheels in the box N. The last of these wheels (termed the "mile"-wheel) makes one revolution while the vessel passes through the water one nautical mile. On the spindle of this "mile"-wheel is affixed a second wheel having eight ratchet teeth, and these teeth, by moving a lever, cause an electric circuit to be completed—obviously eight times in the mile—the current passing through the electric cable O to the indicating dials and bells.

Fig. 166 shows the dial, which has eighty graduations on

Fig. 166.—Dial of Kelway's electric log.

the outside circle, and, as the pointer in front of the dial jumps one graduation at each completion of the electric circuit, one revolution of the larger pointer represents ten miles. Ten revolutions of this pointer cause the small one to make one revolution—recording 100 miles. In fact, the mechanism of this improved form of log is similar to that used in the towing log, to which the inventor's electrical apparatus was affixed, and which was successfully tried on board several of her Majesty's ships.

The Electro-Metallurgy of Zinc.—Several attempts have lately been made to introduce electro-chemical methods into metallurgy. At the Paris Electrical Exhibition magnificent copper plates were shown, obtained by electrolysis on using the masses of copper to be refined as soluble electrodes in a bath of copper sulphate.

Similar attempts have been successfully made with zinc, with the object of extracting this metal from its ores. A special interest is attached to these experiments, because the metallurgical methods for the extraction of zinc from its ores are very expensive, and thus afford a favourable opening for the employment of electricity.

With the ordinary method, which consists in the reduction of zinc by carbon at a high temperature, the expenses amount to about £2 per ton of ore. To this has to be added a loss of one-sixth of the zinc contained in the ore, or about 16*s.* to 25*s.* per ton. The reduction of one ton of the ore, therefore, costs about £3, or 3*s.* per hundredweight, with an ore containing from forty to fifty per cent. of the metal. Besides, if the ore comes from Greece, Sardinia, or Spain, the freight amounts to another 25*s.* per ton. With the object of reducing the cost, the zinc of the ores has been transformed into a soluble salt, and subsequently reduced to the metallic state by electricity.

The two zinc ores used in practice are calamine or zinc carbonate, and blende or zinc sulphide; they are both insoluble, and must therefore be first of all transformed into soluble salts.

Both hydrochloric and nitric acids have been proposed as solvents, but the method lately indicated by Létrange seems to us the most practical, because it is the least expensive. Létrange transforms the insoluble blende into

soluble sulphate by a very simple process, in which the sulphuric acid necessary for the formation of the sulphate is supplied by the ore itself.

It is well known that, by the roasting of sulphur ores, part of the sulphur forms a sulphate, whilst the remainder is given off in the form of sulphur dioxide. This latter can be converted into sulphuric acid in the usual way, and the sulphuric acid thus obtained can be used as solvent for the ore.

The ore, consisting of a mixture of blende and calamine, is roasted at a moderately high temperature, so as to obtain the largest possible quantity of zinc sulphate. The vapours of sulphur dioxide, converted into sulphuric acid, are used either for the solution of the calamine or of the roasted ore.

After the ore has been converted into sulphate, it is placed into large tanks and treated with water. The solution of zinc sulphate passes slowly into another series of tanks, where it is exposed to the action of the electric current. The liquid sulphate sinks slowly to the bottom of the tank, and the sulphuric acid, liberated at the positive electrode, gradually rises to the top, from whence it flows into another tank containing roasted ore or calamine.

A continuous reaction is thus established: the liquid current first passes through the dissolving tanks, where the acid dissolves the zinc contained in the ore to exhaustion, then passes into the precipitating tanks, where it deposits the zinc and changes back into acid, only to be employed again as a solvent.

The same liquid, however, cannot be used *ad infinitum*, because the ores contain oxides—lime, for instance—which do not part with their acids by electrolysis.

The electrodes employed in this method are not

identical, the negative electrode consisting of a thin zinc plate, the positive electrode being formed of a leaden plate. On this latter the iron contained in the liquid is deposited in the form of oxide, which detaches itself and sinks to the bottom of the tank. As regards the lead, the silver, and the other metals insoluble in sulphuric acid, they remain in the residue, from which they can be extracted.

The electric current necessary for these operations is supplied by dynamo-electric machines; and Létrange uses, as much as possible, natural forces for driving them.

In this latter case the operations are reduced to placing the roasted ore in the dissolving tanks, removing the residue, and replacing the electrodes charged with zinc by fresh plates.

When a steam-motor is required, the quantity of coal used for the production of two hundredweight of zinc is the same as for one hundredweight with the ordinary method.

There is an enormous saving too in the original outlay, which for the ordinary method amounts to £40,000 for the production of 20,000 tons of zinc. The new process only requires, for the same production, from 200 to 300 horse-power, a corresponding number of dynamo-electric machines, and a certain number of dissolving tanks. The outlay in this case would not exceed £20,000.

With the view of simplifying his process, Létrange causes the sulphurous acid directly to act upon the oxidized ore or the carbonate, without converting it into sulphuric acid; he thus obtains zinc sulphite instead of sulphate, but this salt is as readily decomposed by the current, and is, moreover, gradually converted into sulphate by the action of the air.

There can be no doubt whatever that this method has a great future.

The Rectification of Alcohol by Electricity.—Naudin has successfully applied Gladstone and Tribe's zinc-copper couple, together with direct electrolysis, to the purification of alcohols; the process has been carried out on a large scale by M. Boulet, of Bapaume-les-Rouen, and has given most satisfactory results.

For certain alcohols the purification is completely effected by the zinc-copper couple; for others direct electrolysis is required in addition to the action of this couple. Naudin has combined the two methods, and his process may be divided into the following stages:—

1. Treatment of the distilled fermented liquor by the zinc-copper couple.

2. Electrolysis of the resulting liquor, with addition of acid, in a series of voltameters.

3. Neutralization of the liquid obtained by the second operation.

4. Rectification by the usual method.

The first stage of the process is effected in closed wooden or copper vats, divided into a number of compartments by perforated wooden troughs on which the zinc filings are placed. The zinc-copper couple is formed by the introduction of a solution of copper sulphate (five parts of the salt to 100 part of the solution) into the vat. The discolouring of the liquid, which takes place at the end of about two hours, indicates the point at which the copper has been precipitated on the zinc; the solution containing zinc sulphate is now removed and replaced by the fermented liquor.

A serpentine tube surrounding the wooden trays allows the circulation of hot water. The fermented liquor enters the vat through a tube at the bottom; as soon as the vat

is full, the tap of the entrance tube is closed, and the tap of a tube at the upper end of the vat, which is connected with a pump is opened. The liquid is kept in continual motion by the action of the pump, and thus brought into intimate contact with the hydrogen given off by the zinc-copper couple.

After a certain time, the length of which depends on the greater or lesser purity of the fermented liquor, this latter is drawn from the vat, acidulated by one-thousandth of sulphuric acid, and introduced into the voltameters. The voltameter is a long narrow glass cylinder hermetically closed at both ends; two tubulatures at the lower end admit two tubes, which reach nearly as far as the upper end of the cylinder. The tube for the entrance of the liquor is closed at the top and perforated throughout its whole length; it is placed between two platinum plates serving as electrodes and connected to the dynamo machine. The second tube, through which the liquor leaves the cylinder, is bent at the top and communicates with the entrance tube of the next voltameter. Several of these voltameters are arranged on the same supporting frame. From the voltameters the liquor passes into vats containing zinc or iron for the neutralization of the acid, and from thence into the ordinary rectifying still.

The most interesting practical result obtained by Naudin with his process is the manufacturing of pure alcohol from beet roots. It is well known that the alcohol hitherto obtained from beet roots is of very bad quality, and that it is next to impossible to purify it; Naudin's electrolytical rectification gave an alcohol of eighty per cent., and of a quality equal to that of alcohol prepared from grains.

ELECTRICAL TRANSMISSION OF FORCE TO A DISTANCE.

THERE is a much more intimate connection than might be thought at first sight between electric telegraphy and the transmission of force to a distance.

An ordinary Morse, for instance, is nothing but an electric motor set in motion by a force frequently placed at a considerable distance, and producing, in most of the cases, mechanical motions.

Even in an alphabetical telegraph this motion is rotatory but discontinuous. It is clear that the energy set in motion under these conditions is excessively feeble, and that for a long time it was not even contemplated practically to utilize this transmission for anything but the production of signals by the agency of comparatively delicate and very light apparatus. The transmission of motive force by electricity bears reference to two distinct questions which we will shortly mention—

1. The production of electricity;

2. The utilization of this electricity in a receiver which converts it into motive force.

The Sources of Electricity.—There was no thought of creating an electric motor capable of producing appreciable work, before the invention of Grove's battery, a few previous attempts excepted, which will be mentioned below. Jacobi's

memorable experiment made on the Neva, in 1839, with a Grove's battery of 128 elements, proved that a certain quantity of work could be produced by electricity. At that time the electrical efficiency of batteries and their mode of utilization were but imperfectly known.

The numerous researches on the voltaic battery made since, enable us accurately to determine the maximum work available in a given element, as well as the fraction of this work which can be utilized, according to the relative conditions of the battery, the circuit, and the electro-motor.

A given battery can be likened to a waterfall. Like this latter, it supplies a flow of a certain volume at a certain pressure during unity of time. The volume is the quantity of electricity which the battery can supply; the pressure is its electro-motive force.

The maximum work which our waterfall can supply during unity of time is equal to the product of the volume of the flow of water by the height of the fall. In the same way, the maximum work which a battery can supply is equal to the product of the quantity of electricity by the electro-motive force.

There is, therefore, already a theoretical limit which cannot be exceeded and still less be attained, for the losses of current in the conductor and the efficiency of the motor must be taken into account. This efficiency varies with the speed of the motor, and modifies to a very great extent the relation between the electrical energy expended and the mechanical work produced. To this must be added that the battery consumes a very dear fuel—zinc, and that it consumes it but slowly.

It follows from this that the battery, considered from the point of view of electrical energy displayed, is very expensive,

very heavy, and very cumbersome. This will sufficiently explain why electric motors set in motion by batteries—whatever may be their system—have up to the present not given the results which were expected of them at the beginning, and also why they have hitherto found but few applications for producing forces not exceeding a few kilogrammetres.

We will quote a few instances of this.

If electrical accumulators are used as the source of electricity, the question assumes a different aspect. Where very small forces are required, at irregular intervals and with long periods of rest, representing altogether a very small amount of energy, accumulators can be employed. A series of accumulators weighing one hundred kilogrammes will feed a sewing-machine for a week, with an average work of from two to three hours per day. By charging these accumulators by means of dynamo-electric machines, and taking them, when charged, to the place where they are to act, the working will be found fairly advantageous from an economical point of view, provided that there exists a general system for the distribution of electricity. Accumulators can also be used where it is a question of utilizing natural forces which vary at each moment, like wind and tide; in that case they act the part both of reservoir and of regulator. But this is a question of transport and distribution of force to a distance, and no longer of a motor fed by an electrical source; but this question we reserve for future consideration.

ELECTRIC MOTORS.

THE first attempt to create electric motors dates back, according to Figuier, to 1831, and is due to the Abbé Salvator del Negro, of Padua. At that time, only single-liquid batteries were known, and Del Negro's motor could not give satisfactory results, were it only for the inconstancy of the source. The invention of Grove's battery, which provided a comparatively powerful electrical source, was the starting-point for new experiments, of which Jacobi's was the first in date.

In 1840, Messrs. Patterson brought before the Académie des Sciences an electric motor, to be used for printing a weekly paper, but which was in reality no good at all. In 1842, Davidson pretended to have worked a locomotive of eight tons, with a speed of eight kilometres (five miles) per hour on the line between Edinburgh and Glasgow, but the truth of this assertion is as little proved as Page's advertisement, in 1850, of a motor capable of producing work amounting to five horse-power.

A large number of motors invented since Page's experiments are described in Du Moncel's *Exposé des Applications de l'Électricité*. These motors only present a purely retrospective interest. In reality, none of them has produced work exceeding four kilogrammetres; they must be considered as electrical toys, for most of them only produce a fraction of a kilogrammetre.

Nowadays electric motors are employed under conditions much more favourable for their effective working. Thus, for instance, motors with reciprocating motion have been justly discarded, as they were not fitted for great speed. All modern electric motors are rotating. We take as a type Marcel Deprez's motor, which, for the production of small forces, has given very satisfactory results, considering its weight and its dimensions.

Marcel Deprez's Electric Motor.—The apparatus represented in Fig. 167 is nothing but a Siemens' bobbin B moving

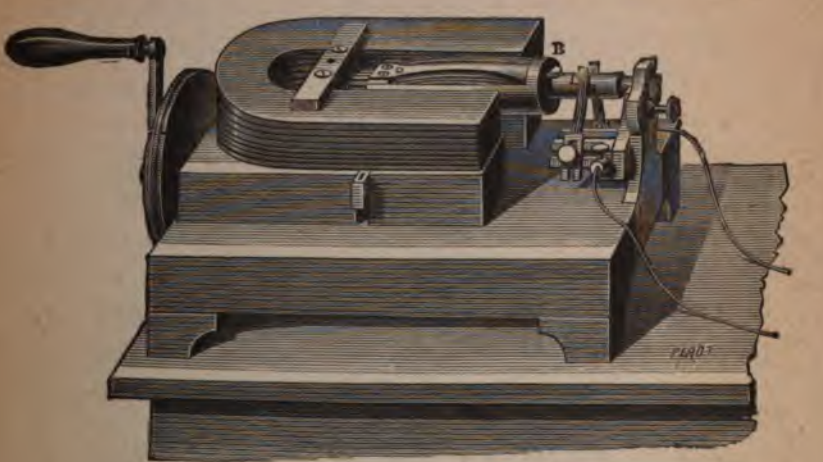


Fig. 167.—Marcel Deprez's magneto-electric motor.

between the arms of a magnet. By placing the bobbin longitudinally between the arms of the magnet, instead of placing it transversely as Siemens has done in his machines, Deprez utilizes all the power of the magnet, and makes the motor lighter and less expensive for equal power. The current of the source arrives at the contact pieces of the commutator by two brushes formed of very fine brass wire, as in Gramme's machine. The current which traverses

the bobbin changes at each semi-revolution, at the moment when the poles which it polarizes pass before those of the magnet. The poles of the same sense repel each other, those of contrary sense attract each other, and the bobbin receives a rotatory motion depending on the sense of the passing current. The brushes are mounted on a support which can turn round the axis of the bobbin. The wedgings of the commutator and the speed of the motor can thus be changed according to the effect which it ought to produce. The model of Fig. 167 has a magnet of 1700 grammes, the bobbin weighs 400 grammes, and the weight of the complete motor is below four kilogrammes. For a speed of 3000 revolutions per minute it produces 2·5 kilogrammetres with eight flat Bunsen elements (Ruhmkorff's model). When the speed tends to become too great, a small spring, fixed by one of its ends to the wire of the bobbin and pressing with its other end against one of the contact pieces of the communicator, is withdrawn from this contact by the effects of centrifugal force. The circuit is opened and remains open until the speed becomes normal again. In practice, the opening and closing of the circuit succeed one another so quickly that the variations of speed do not exceed $\frac{1}{100}$ of the normal speed.

Trouvé's Motor.—Deprez's motor is magneto-electric, that of Trouvé is dynamo-electric. A Siemens' coil revolves between the branches of a flat U-shaped electro-magnet. The exterior faces of the coil are slightly eccentric, which does away with the dead point. Trouvé has placed his motor on the helm of a small boat; the cords which direct the helm serve at the same time as conductors, and the current is supplied by a bichromate battery placed in the centre of the boat. The helix driven by the motor is placed

on the rudder and turns with it, and the boat therefore performs its movements with the greatest ease.

Trouvé's motor has been applied by Journeaux to a sewing-machine; it is fed by three Faure's accumulators.

The motor (Fig. 168) is placed vertically; its axle carries a pulley lined with indiarubber, which presses against the fly-wheel of the machine and drives it. The pressure of the pulley against the fly-wheel is regulated by means of a spring. The machine can be disconnected

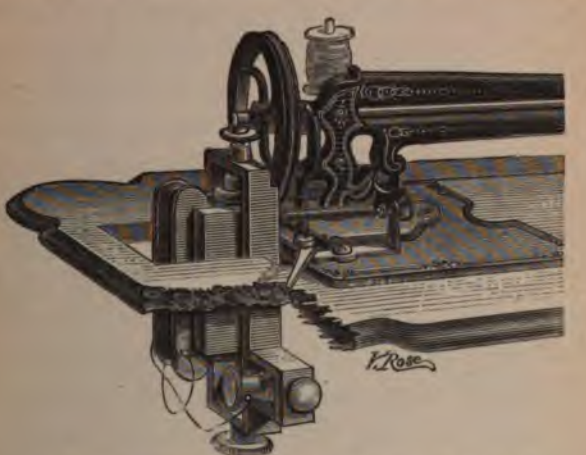


Fig. 168.—Trouvé's motor applied to a sewing-machine.

from the motor by means of a small square lever, which removes the motor; the contact between the pulley and the fly-wheel is broken, and the machine can be worked with the treadle. This is very useful if the accumulators are, for some reason or other, not charged. The commutator for setting the machine in motion or for stopping it is worked with the treadle.

The speed is regulated by exercising more or less pressure on the same treadle. This pressure produces a gradu-

ated pressure on a chain composed of a number of silver rings, which is interpolated in the circuit of the motor and of the electric source. A series of microphonic contacts is thus obtained, which, by their varying resistance, modify the intensity of the current and consequently the speed of the machine. This ingenious contrivance is due to M. E. Reynier.

Griscom's Motor.—This motor has been specially constructed for driving sewing-machines. Its length does not exceed ten centimetres, and its weight 1150 grammes.

It consists (Fig. 169) of a Siemens' coil revolving between the two poles of an annular electro-magnet with consequent points; it is thus entirely enclosed in the inductor which protects it. All the pieces are of malleable cast iron, which has as feeble a coercive force as soft iron. This motor can easily be fixed on all existing machines by means of a small, straight or square support, and a small screw-nut placed at the bottom.

The electric generator employed by Griscom is a bichromate battery of six elements. The speed of the motor is regulated by immersing the elements more or less into the liquid, by means of a pedal placed on the side of the box which contains the elements; a single charge is sufficient, according to Griscom, to do from 500 to 1000 metres of sewing, within a fortnight or six months of charging, at irregular intervals.

It would lead us too far afield to describe all the small motors which figured at the Paris Electrical Exhibition. The development of their applications seems to us altogether subordinate to the distribution of electricity.

Motors with Siemens' coil and their various modifications are very serviceable where inexpensive machines of

feeble intensity are required. They, however, present a drawback which limits their employment to small forces. In these motors, the current supplied by the electric source is not continuous; it is interrupted at the moment when the current changes its direction in the coil, and likewise if the ferrules of the commutator are in very close proximity; a direct communication is established by the brushes at

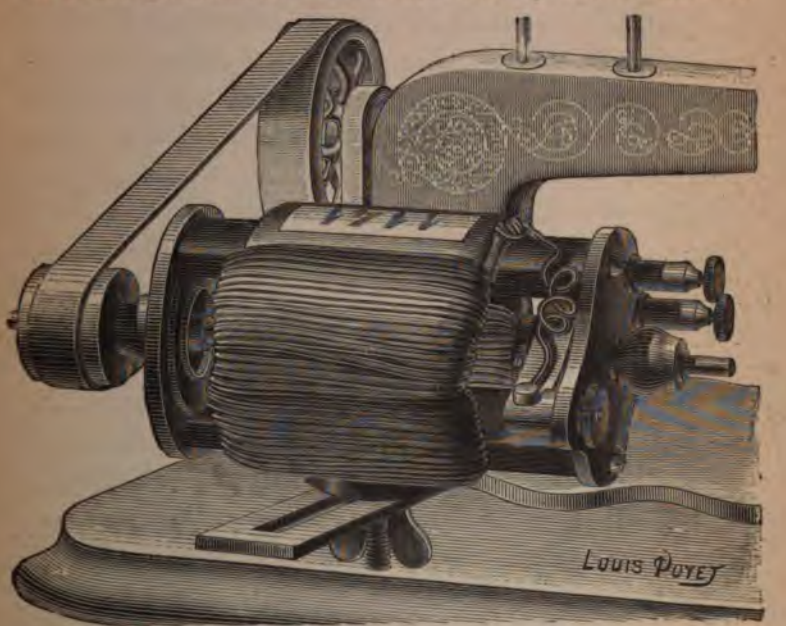


Fig. 169.—Griscom's electro-motor.

each semi-revolution, thus short-circuiting the electric source and increasing the expense at the very moment when it produces no work. In either case, the discontinuity of action is unfavourable to the efficiency, and all the motors we have described are therefore inferior, as regards their efficiency, to electro-dynamic machines acting as motors.

The advantage of dynamos or continuous machines over motors with Siemens' coil has been generally admitted by this time, and M. Gramme is at the present moment busily engaged in constructing small dynamo-electric machines for the production of feeble motive power.

Reversibility of Electro-Dynamic Machines.—It is well known that, when an electro-dynamic machine is set in motion, it produces an electric current. Inversely, if a current passes into an electro-dynamic machine, it is set in motion.

In the first case work is transformed into electricity, and in the second electricity is transformed into work. This fact is expressed by saying that electro-dynamic machines are reversible. It follows from this that, since dynamos with Gramme's ring produce continuous currents, they also expend a continuous current, and will be under the most favourable working conditions when supplied with a continuous current by the electrical source.

The principle of reversibility, introduced by Carnot, has not only simplified the electrical transmission of force to a distance, but has also rendered the methods infinitely more economical; there has hardly been time yet to appreciate these advantages.

Compressed air, canalization of steam or gas, distribution of water, tele-dynamic cables, etc., partly solve the problem in particular and special cases; none of these modes of transmission, however, affords such a general solution as electricity, which, by means of contrivances of the extremest simplicity, can produce, according to the requirements, heat, light, motive force, or chemical actions.

We shall only here consider the case of transmission of force to a distance, and the applications resulting from it. The other cases come under the distribution of electricity.

The transmission of force to a distance is based upon the reversibility of magneto and dynamo-electric machines. This principle can be thus expressed—

All machines which produce electricity by expending work can, inversely, produce work by expending electricity.

The applications of the electrical transmission of force to a distance—for ploughing, traction of engines, pumping of water, piercing of rocks, driving of machines in a workshop, etc., are all based on this general principle. All continuous-current machines enable us to effect this transmission, and the practical realization is merely a question of expense.

As a case in point, let us take a magneto-electric generator, driven with a constant speed by a hydraulic or steam motor, and connected by means of a conductor to a second, receiving, machine acting as motor.

Let us first of all suppose the resistance of the interpolated conductor to be so feeble that it can be neglected, and let us increase it by removing the motor. The generator produces a certain electro-motive force E. The receiver generates by its rotation an electro-motive force E^1 of inverse sense to that of the generator. Having admitted this, it can be proved that, if both machines are removed, the efficiency, that is to say, the relation between the work expended and the work produced, is constant, whatever may be the resistance of the interpolated conductor. The lengthening of the conductor simply affects the quantity of work expended and the quantity of work produced, without changing their relation.

In order to transmit the same amount of work to a longer distance, the electro-motive force of the two machines must be increased.

The only limit which exists in practice is the insulation of the line and the machine wires.

Marcel Deprez has proved that with two similar fine-wire dynamos, one of which produces an electro-motive force of 7000 volts, and expends sixteen horse-power, ten horse-power can be obtained in the second machine by employing as conductor an iron wire of four millimetres diameter. The efficiency would then be sixty-five per cent.

Quite recently Maurice Lévy, by carefully regulating the relative resistances of the two machines, obtained an efficiency of seventy-five per cent. for the same distance and the same initial electro-motive force of the generator. The electrical transmission of force to a distance can, therefore, be realized under the most economical conditions, and there is no doubt that before long natural sources of power which have hitherto been wasted will be utilized for this purpose.

It is not so much a question of utilizing the Falls of Niagara, and spreading the enormous amount of work which they represent over a part of America, but, on a smaller scale, the system of electrical transmission of natural forces to a distance will render valuable services in industrial establishments situated near large waterfalls, rivers, streams, etc.

The utilization of natural forces for the generation of electricity has scarcely advanced beyond the state of a theory, while electricity as a mode of transmission of force to a distance has found a number of practical applications, gas or steam motors being used for driving the generator.

It would be very difficult to decide who started the idea of the principle of reversibility of electro-dynamic machines, but the first application of this principle was

made by Fontaine, at the Vienna Exhibition, in 1873, with two Gramme's machines, one of which, the generator of electricity, was worked by the general motive power supplied on the spot, and the other, receiving the current supplied by the first, worked a rotating pump placed in the annex. Other applications have been made at the arsenal of Saint Thomas d'Aquin, and at M. Cadiat's, who transmitted fifty kilogrammetres to a distance of 150 metres with two Gramme's machines (workshop type), the first constituting the electrical source and the second the motor. Chrétien and Félix, in 1878, used Gramme's machines for unloading boats and loading waggons, the source of electricity being placed at 100 metres from the place of loading or unloading.

Ploughing by Electricity.—A public trial of this application was made at Sermaize, on the 22nd of May, 1879. The annexed Plate represents the principal features of this interesting experiment.

Two four-wheeled trucks placed on each side of the field receive the electricity, supplied by Gramme's machines by the aid of conducting wires.

A commutator sends the electricity alternately into the two trucks. These trucks are each moved by two Gramme's machines. Each of these machines has a pulley surrounded by a caoutchouc ring, which presses against a fly-wheel with a polished surface, and carries it along; the pressure between the fly-wheel and the ring is regulated by a spring connected with the movable supports of Gramme's machine. The trucks guide in turns one plough with four ploughshares, two of which work in one sense; the cable of steel wire which pulls the plough is wound up on one side, while it unwinds itself on the other, and *vice versâ*. When the

double furrow is made, the two trucks are moved by transferring the action of the Gramme's machines from the plough to the hind wheels of the trucks, which then take up a fresh position ready for making a fresh double furrow. This experiment proves that motive force can be transmitted to considerable distances by electricity.

This application will prove most advantageous where an inexpensive motive force is supplied by water-power, as is the case in Menier's electrical works, at Noisiel. The available mechanical work can, under these conditions, be utilized for ploughing and other kinds of agricultural labour. In the neighbourhood of certain factories—sugar refineries, for instance—where steam motors stand still for a great part of the year, it will be most advantageous to use electrical ploughs to utilize the motors. In cases where special machinery is required, the advantage seems to us very problematical.

Electric Railways.[1]—Electric railways entirely depend upon the distribution of electricity by means of convenient electrical centres. The experiments made in 1879 at Berlin, and last year at Paris, show that the question is practically solved; in fact, an electric railway has lately been established at Berlin. The first experimental railway constructed at Berlin in 1879 is represented in the Frontispiece.

The problem was completely solved by MM. Boistel and Sappez, the engineers of Messrs. Siemens. In the preliminary experiments made at the workshop in the Rue Pictot, they made use, as conductors, of a brass tube electrically connected with the carriage by a traverser, the function of which we shall explain; the wheels and rails will serve as return wire. This system worked well at the

[1] From *Nature*, 1881.

workshop. In practice a special difficulty was encountered. The dirt sticking to the rails and felloes of the wheels formed a sort of crust so insulating as to prevent adequate communication with the earth. The increase of resistance produced by this interposition of finely conducting bodies was often sufficient to arrest the vehicle. The remedy was happily beside the evil, and a second conductor was established parallel with the first, in communication with the second pole of the generator, on which runs a second traverser identical with the former. These two cars follow on their respective tubes the movements of the vehicle, and ensure a good and constant communication between the electrical generator and the motor. At the height of the knife-board are two conducting tubes supported at certain distances by posts, and in the intervals by iron wires like the floor of a suspension bridge. The carriage is exactly the same as the ordinary tramway car. The motor is placed underneath the feet of the inside passengers; it is a Siemens' dynamo-electric machine with horizontal inductors. The distance traversed was about 500 metres, and was accomplished in one minute. The work expended reaches eight horse-power in the curved part; on a level straight run it does not exceed three and a half horse-power. The transmission of motion to the wheels is effected by means of a fall-chain. By a happy coincidence, which belongs to the very nature of the electric motor, the static effect is maximum when the motor is in repose. This renders the starting very easy, and no difficulty is met with from this point of view. To regulate the speed, resistances are introduced into the general circuit, which reduce the intensity of the current, and consequently the work of the motor; this operation is very simply effected

by means of a lever placed at each end of the carriage. For stopping, the current is broken, and at the same time an ordinary brake is applied.

As to the mode of communication of the conductors with the carriage, we have said that it is effected by means of two identical traversers; it will suffice to describe one of them. It is composed of a rectangular frame, bearing in its centre a wheel, of which the groove is semi-cylindrical, and is applied against the exterior part of the conductor, formed of a brass tube twenty-two millimetres in diameter, and slit on its lower part along all its length to a breadth of about one millimetre. In this tube slides a cylindrical core twelve centimetres in length, on which are fixed, at its extremities, two vertical shafts, which support the wheel or roller. Two springs supported on these vertical shafts press the wheel against the tube, and maintain an elastic contact between the tube and the wheel. The carriage may then be moved; the wheel runs against the tube; the core glides in the interior, without the communication ceasing to be, if not perfect, at least quite sufficient for the purpose. Only at times a few sparks are seen at the moment when the carriage passes the coupling of the tubes; these sparks are due to small instantaneous ruptures of the current, which do not affect the working of the system. The experiment shows that the wear and tear scarcely affects the tube; but nothing is easier than to replace a core. The current reaches the machine by a copper conductor. The traction of the carriage is effected by cords, according to the direction.

The electric railway of the Palais de l'Industrie presents a practical solution of an electric traction in the case of a tramway. Of course, it is easy to see how this

application of electricity is capable of the greatest development, and that by modification of details the principle might be applied to railways.

Various Applications.—Among the various applications of electrical force exhibited at Paris, we have to mention the apparatus for the piercing of rocks, either by percussion or rotation, the hoisting apparatus for mining and quarrying, the pumping of water by means of Greindl's and Dumont's rotative pumps, electric lifts, the working of the ventilators in the telephone-rooms, etc.

According to the force required and the nature of the work to be performed, the forms and dimensions of the machines have to be modified.

The question of transmission of electrical force simply resolves itself into a question of expense, whether it be cheaper to generate electricity at a distance and convey it to the consumer, or to produce it on the spot by means of some motor or other.

THE DISTRIBUTION OF ELECTRICITY.

THE infinite variety of applications to which the electric current so easily lends itself, daily adds fresh importance to this comparatively new question. We give in the following lines a brief account of the actual state of this question, and of the future in store for the distribution of electricity.

It is well known how readily electrical energy produces, according to individual requirements, light, work, chemical effects, and even heat, especially very high temperatures.

As soon as practical and inexpensive methods shall have been introduced for supplying the energy to the consumer in any desired quantity and for instantaneous use, as water and gas are distributed nowadays, the number of electrical appliances will increase with a rapidity without precedent in history. The problem not only is capable of being solved, but has been partly solved already.

Generally speaking, this problem resolves itself into one of canalization, or of establishing a network, fed by a number of electric generators, which are set up at different points of the area to be supplied, and arranged in such manner that each electric receiver—electric lamps, motors, bells, galvano-plastic troughs, lighters, electric stoves, etc.—receives the necessary quantity of electricity, and under the most favourable conditions of electrical pressure. The stoppage at any moment, or the working of an indefinite number of receiving apparatus must in no way affect the

electrical circulations in all the other apparatus which are in active work. This will be the case when all the apparatus of the system work with electrical pressures E and intensities I of different value for each of them.

No system of distribution employed at the present time solves the problem thus generally put; that it is capable of being solved we shall show presently. The simplest case is where all the apparatus are identical, that is to say, are worked under the same conditions of volume and pressure. The division of light affords several examples of this case. The arc lamps of Brush, Gramme, Siemens, Weston, Berjot, and the incandescent lamps of Edison and Maxim, present partial solutions, to which we need not refer again.

In the case of a variable expenditure of energy, each apparatus must be supplied with a quantity of electrical energy equal to the product of the volume by the pressure, that is to say, equal to EI.

The problem is simplified by having one of the two factors constant, and varying the other according to the requirements of the case. Hence we have two large general systems of distribution—

1. Distributions with constant pressure.

2. Distributions with constant volume or intensity.

Distribution with Constant Pressure.—Let us suppose that, by some method or other, we can maintain between two points, A and B, a constant pressure or difference of potentials. An indefinite number of circuits may branch off between these two points. Each of them will be traversed by a current with an intensity expressed by Ohm's formula—

$$I = \frac{E}{R}.$$

E being the difference of electrical pressure between the two points A and B, R being the resistance of the circuit.[1]

Let us suppose, for instance, the pressure between A and B to be 100 volts; by introducing an incandescent electric lamp between these two points, the intensity of the passing current will be—

$$I = \frac{100}{100} = 1 \text{ ampère.}$$

If, on the other hand, we interpolate an arc lamp with a total resistance of only four ohms, the intensity of the current will be—

$$I = \frac{100}{4} = 25 \text{ ampères.}$$

The electrical pressure will be the same in both cases, but the energy expended by the arc lamp will be twenty-five times as great as that of the incandescent lamp, because the intensity of the current will be twenty-five times as great. By maintaining a constant pressure, and conveniently varying the resistance of the receivers, we have therefore a means of varying the consumption of each receiver. For an electric bell, for instance, we lead off to an electro-magnet with an excessively long wire of great resistance; the expended energy will then be very feeble, and the bell can be worked by the main current of the system. This system, therefore, requires all the apparatus branching off from the main current to be placed on shunts between the two points A and B, and these shunts must have a constant difference of potential or of electrical pressure. In practice all the shunts need not be taken from the two points A and B.

[1] We must sometimes—in the case of an electro-motor, for instance—take into account the antagonistic force developed in the receiver. We merely mention this point here, the introduction of this factor would complicate our explanation.

By combining the resistances of the apparatus, and connecting two main conductors of sufficiently large size to the points A and B, the shunts can be taken from any part of the conductors without sensibly affecting the results.

The problem consists in maintaining the electrical pressure constant between the points A and B.

Edison's and Maxim's systems partly realize these conditions for lighting with the incandescent lamp.

Let us now pass on to the systems proposed for a general distribution. The most rudimentary is the one proposed by Gravier, in April, 1880. Gravier employs no current regulator. He excites a number of machines separately, and mounts them all for quantity to diminish the interior resistance. Theoretically speaking, if there were no interior resistance in the generators, an indefinite number of circuits might lead off from these generators without affecting the intensity of circulation in the remaining circuits. This is a method of distribution which was worked with favourable results at the Paris Electrical Exhibition, with a limited number of circuits, but it is not a general solution of the problem.

The author of this book proposed, in September, 1880, a complete system of distribution, which, however, has not been carried out yet.

Finally, the most recent solution by constant pressure was proposed by Marcel Deprez, and carried out at the Paris Electrical Exhibition, for distributing energy to a number of motors of different power. In this highly ingenious system no mechanism for regulation is required, the regulation being effected automatically and instantaneously by the introduction of new shunts into the circuit. For this purpose the dynamos placed on a

common shunt have inductors coiled with two distinct wires. One of the wires is placed in the circuit of a special exciting machine, the other is in the general circuit. The intensity of the magnetic field in which the armature revolves depends, therefore, not only on the constant current supplied by the exciting machine, but also on the variable current of the general circuit. The increase of intensity of this current for each additional shunt introduced into the circuit, increases the electro-motive force of the quantity required for maintaining the useful electrical pressure, which is perfectly constant between certain limits.

This elegant solution is thoroughly effective in the case of one single distributing workshop; it remains to be seen how it will act in the case of a general system of distribution with a number of workshops.

Distribution with Constant Intensity.—This system was originally proposed by Cabanellas, in December, 1880. All the receivers are placed, one after another, in the same circuit. The main current traverses them all with a constant intensity. There is a regulator at the central workshop for varying the electro-motive force of the generators, in order to maintain this intensity constant. It is clear that less initial pressure is required when the circuit is short, and only a few apparatus are interpolated in that circuit, than when all the apparatus are at work, and also that the methods for stopping or setting in action a given receiver must naturally be the very reverse of the methods used for the systems which employ shunted currents or constant pressure. In the one an apparatus is suppressed by breaking the circuit; in the other, on the contrary, this operation is performed by establishing a direct communication between the two terminals, that is to say, by short-

circuiting the receiver. The current then passes directly into the shunt, without traversing the receiver. At the central workshop, an automatic mechanism introduces or suppresses the individual machines as occasion requires, increasing thereby or diminishing the initial electromotive force, and thus maintaining a constant intensity. Cabanellas thus establishes a series of separate and closed circuits, going from house to house, from story to story, to supply the various apparatus of his system. Each circuit, naturally, has its own regulator, absolutely independent of that of all the others.

Advantages and Drawbacks of the Two Systems.—The system with constant pressure more effectively ensures the independence of the individual circuits, for there is no common connection between the apparatus as in the system with constant intensity, where they are placed one after another in the same circuit.

In fact, the least accident to the conductors or to a receiver in a given circuit deprives all the receivers in the same circuit of their current power. This is a most serious drawback, a drawback which does not occur with constant pressure, because each shunt is entirely independent of the others. Numerous contrivances, however, have been invented for localizing the accidents which might occur. Of these we will only mention Edison's safety-box, described on p. 243.

The shunt system requires comparatively thick conductors, especially at the point of departure from the central workshop. The thickness of these conductors must, from the outset, be adapted to the probable number of shunts required, in order not to be obliged to disturb the canalization in the case of an increased consumption. But

this system allows us to work with electro-motive forces which are of comparatively feeble intensity, and therefore less dangerous, and which also require a less perfect insulation of the conductors than in the system with constant intensity, where the conductors are charged for a high potential, and constitute a permanent source of danger.

It is impossible, at the present moment, to assign any marked preference to either of the two systems; the question of distribution of electricity is still in its infancy, and the future alone can decide this point.

Electric Transformers.—Whether the distribution be effected by constant pressure or by constant volume, all the apparatus cannot be indiscriminately adapted to this indispensable constant factor. Thus, for instance, if a distribution is effected by constant pressure, with an available fall of 200 volts, this initial fall will be too great for the supply of an arc lamp of average intensity or for galvanoplastic; nor will it be possible, with the current supplied, to feed Jablochkoff's candles, which require an alternating current.

All apparatus which enable us to change the qualities or the nature of the currents supplied by a system of distribution, for the purpose of adapting them to the exigencies of the receivers, are transformers. Planté's accumulator and Ruhmkorff's coil are transformers. They have been described in Part I.

We will only here say a few words about some transformers specially applied to an electrical distributing system.

Cabanellas' Electric Tap.—Let us suppose, at a subscriber's house, an electro-motor of a certain power, supplied by the system. This electro-motor, in its turn, can

drive an electric generator which, according to the special requirements, will give a continuous current of large volume for galvano-plastic, or a high-tension current for Geissler's tubes, or an alternating current for Jablochkoff's candles. Such a transformer has only one defect—the transformation is effected by the intermedium of work, and serious loss is the consequence. To diminish this loss, Cabanellas has constructed much simpler transformers, which do not pass through this intermediate stage of work, and fulfil the functions both of dynamo-electric machines and of induction coils. By means of these transformers, whatever may be the mode of distribution adopted and the elements of distribution, it will always be possible to feed a receiver of any kind, provided the transformer expends a quantity of electrical energy slightly superior to that which is consumed by the receiver.

Webermeters.—It is of the greatest importance to determine and to register the electrical energy supplied to each consumer. In the system with constant pressure, it is sufficient to know the quantity of electricity which has passed through the circuit of each subscriber. This is very easily done by interpolating a voltameter with copper sulphate in a shunt on two points very close to the conductor. Only a very feeble part of the main current passes into the voltameter. The proportion of current power can, moreover, be regulated by a convenient arrangement of resistances. By weighing the copper deposited on one plate in excess of the other during a fixed time—a month, for instance—we have all the necessary elements for determining the quantity of energy supplied to each subscriber, and consequently for charging him, in a similar manner as for a supply of gas.

This is the principle of Sprague's and also of Edison's apparatus. The latter has also constructed a more complicated, self-acting webermeter, which dispenses with the weighing of the plates.

We have had to content ourselves with casting a rapid glance over a number of interesting problems connected with the distribution of electricity, and its manifold applications. The enumeration of these applications alone would occupy a considerable space. We only wished to show that the question is ripe, and that there are no insurmountable obstacles in the way of a complete solution.

In a few years electricity will have penetrated into our houses, bringing with it innumerable and undreamt-of comforts, and thus keeping pace with the ever-increasing requirements of modern civilization. The nineteenth century will not come to its close without witnessing an enormous development of the applications of electricity, and its general distribution for domestic purposes. Our grandchildren, in token of their gratitude for the progress of a science born with the century, will then justly call it, "The Century of Steam and of Electricity."

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*** Abbreviations: *Cont.-cur. mach. = continuous-current machine; alt.-cur. mach. = alternating-current machine; self-exc. mach. = self-exciting machine.*

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